



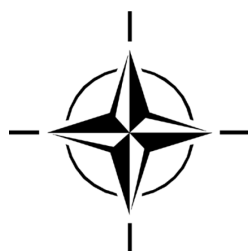
STO TECHNICAL REPORT

TR-SAS-119

Energy and Defence: Reducing Dependencies and Vulnerabilities – Enhancing Efficiency

(Énergie et défense: réduire les dépendances
et les vulnérabilités, améliorer l'efficacité)

Final Report of the NATO SAS-119 Research Task Group.



Published May 2020





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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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List of Acronyms

AMMPS	Advanced Medium Mobile Power Source
APMs	Auxiliary Propulsion Motors
APS	Auxiliary Propulsion System
AWH	Army Water Heater
BCU	Battery Control Unit
BTUH	British Thermal Units per Hour
CSV	Comma-Separated Values
CWB	Conformal Wearable Battery
DPGDS	Deployable Power Generation and Distribution System
DWEC	Deployable Waste-to-Energy Conversion
ECU	Environmental Control Unit
EHAP	Energy Harvesting Assault Pack
ESM	Energy Storage Module
ESMA	Innovative Energy Solution for Military Applications
EST	Energy Storage
EWPS	Expeditionary Water Packaging System
FMS	Fuel Management System
GTG	Gas Turbine Generator
GUI	Graphic User Interface
HED	Hybrid Electric Drive
HEPS	Hybrid Electrical Power System
HyPER-FST	Hybrid Power Emissions Reduction – Fuel Savings Technology
ICAS	Integrated Condition Assessment System
IECU	Improved Environmental Control Unit
ISO	International Organization for Standardization
LAMPS	Large Advanced Mobile Power Sources
LED	Light-Emitting Diode
LHD	Landing Helicopter Dock
LNG	Liquified Natural Gas
M&S	Modeling and Simulation
MCS	Machinery Control System
MIL-STD	Military Standard
MoD	Ministries of Defense
MOM	Measures of Merit
NATO	North Atlantic Treaty Organization
NSPA	NATO Support and Procurement Agency

OE	Operational Energy
OEIDB	OE Initiatives Data Base
PDISE	Power Distribution Illumination System
POC	Proof of Concept
PV	Photovoltaic
REMULES	REnewable Mobile Ultra Light Energy System
RTG	Research Task Group
SEEDS	Smart Energy Efficient Deployable Shelters
SENT	Smart Energy Team
SFC	Smart Fuel Cell
SGQ	Single Generator Operations
SHC	Space Heater Convective
SPACES	Solar Portable Alternate Communications Energy System
SSL	Solid State Lighting
STO	Science and Technology Organization
SWRS	Shower Water Reuse System
TAP	Technical Activity Proposal
TQG	Tactical Quiet Generator
TRAC	The Research and Analysis Center
TWDS	Tactical Water Distribution Equipment System
TWPS	Tactical Water Purification System
WPS	Wearable Power System

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Energy and Defence: Reducing Dependencies and Vulnerabilities- Enhancing Efficiency

(STO-TR-SAS-119)

Executive Summary

Background By being a large consumer of energy, especially fossil fuels, the armed forces of most Allied nations are highly dependent upon imports from countries that are located in unstable regions beyond Allied influence. Developments during the latest decades have put the issue of energy on the NATO security agenda. Within that agenda, NATO's focus is on three major areas:

- 1) Raising strategic awareness of energy developments with security implications;
- 2) Contributing to the protection of critical energy infrastructure; and
- 3) Enhancing energy efficiency in the military.

Overarching Objectives The NATO Systems Analysis and Studies 119 (SAS-119) Research Task Group (RTG) focused on the third major area indicated above, reducing dependencies on energy resources outside of the Alliance by enhancing energy efficiency through applied technical solutions, focusing on Operational Energy (OE).

Approach

- 1) SAS-119 RTG approached this project as a simple and basic research project. Our primary task was to gather and collect information and data on successfully demonstrated or implemented OE initiatives at operational and tactical levels. The information and data that the RTG collected was used to build a searchable OE Initiatives Data Base (OEIDB).
- 2) Parallel to the data collection effort was designing a way for users to interact with the OEIDB in order to perform customizable queries and easily view results. To accomplish this, the RTG:
 - a) Determined metrics (Measures Of Merit (MOM)) based on attributes of the initiatives to use for assessing their relative goodness.
 - b) Developed a user interface that utilizes the metrics to produce customizable queries reflecting relative comparisons of the initiatives.
 - c) Explored options and made recommendations for an appropriate home for this searchable OEIDB, including recommendations for an appropriate software platform and dashboard for containing and querying the OEIDB, and an appropriate organization to maintain the server and manage access to the OEIDB.
- 3) This research effort was further scoped to the following three areas of interest. These areas of interest represent a subset of the areas of interest provided to the RTG in the Technical Activity Proposal (TAP) guidance document:
 - a) Energy efficient base camps;
 - b) Energy efficiency improvements for ships;
 - c) Soldier-wearable technology and Soldier power.

Status and Recommendations The RTG has accomplished all of the tasks described in the above approach and recommends that the information contained in the OEIDB be made available to appropriate representatives from the governments of the NATO member nations, allies and partners via a webpage on the internet, utilizing the R Shiny application as the dashboard and Graphic User Interface (GUI) for the webpage, and that the OEIDB and webpage reside on a server located at the NATO Energy Security Centre of Excellence in Vilnius, Lithuania. With these recommendations, the primary effort of the NATO SAS-119 RTG is concluded. Analysts from the U.S. will continue to be engaged and work with the points of contact at the NATO Energy Security Centre of Excellence in Vilnius, Lithuania, to get the OEIDB webpage up and running.

Énergie et défense : réduire les dépendances et les vulnérabilités, améliorer l'efficacité

(STO-TR-SAS-119)

Synthèse

Contexte Étant donné qu'elles consomment beaucoup d'énergie, en particulier des combustibles fossiles, les forces armées de la plupart des pays alliés dépendent fortement des importations de pays situés dans des régions instables hors de la sphère d'influence des Alliés. L'évolution de ces dernières décennies a placé la question de l'énergie à l'ordre du jour de la sécurité de l'OTAN. Face à cette question, l'OTAN se focalise sur trois domaines essentiels :

- 1) La sensibilisation stratégique aux évolutions en matière d'énergie ayant des implications de sûreté ,
- 2) la contribution à la protection des infrastructures critiques de l'énergie , et
- 3) l'amélioration de l'efficacité énergétique au niveau militaire.

Objectifs généraux Le groupe de recherche (RTG) SAS-119 de la Commission d'analyse et étude des systèmes s'est focalisé sur le troisième grand domaine indiqué ci-dessus, à savoir réduire la dépendance aux ressources énergétiques hors de l'Alliance en améliorant l'efficacité énergétique par des solutions techniques appliquées et en se concentrant sur l'énergie d'usage (OE).

Approche

- 1) Le RTG SAS-119 a abordé ce projet comme un projet de recherche simple et basique. Notre principale tâche a consisté à réunir et collecter des informations et des données sur les initiatives démontrées ou mises en œuvre, relatives à l'OE aux niveaux opérationnel et tactique. Les informations et données recueillies ont servi à construire une base de données consultable des initiatives portant sur l'OE (OEIDB).
- 2) Parallèlement à la collecte des données, le RTG s'est attelé à la conception d'un mode d'interaction des utilisateurs avec l'OEIDB, afin de présenter des requêtes personnalisables et de consulter facilement des résultats. Pour accomplir cela, le RTG :
 - a) A défini des indicateurs (mesures de mérite, MOM) à partir d'attributs des initiatives, servant à évaluer leur validité relative.
 - b) A développé une interface utilisateur qui utilise les indicateurs pour produire des requêtes personnalisables reflétant les comparaisons relatives des initiatives.
 - c) A étudié les options et émis des recommandations quant à l'hébergement adéquat de cette OEIDB consultable, notamment des recommandations sur une plateforme logicielle et un tableau de bord adaptés permettant de contenir et interroger l'OEIDB, et l'organisation appropriée pour entretenir le serveur et gérer l'accès à l'OEIDB.
- 3) Ces travaux de recherche ont de plus porté sur les trois domaines suivants. Ces domaines forment un sous-ensemble des domaines fournis au RTG dans le document d'orientation de la proposition d'activité technique (TAP) :

- a) Camps de base économes en énergie.
- b) Amélioration de l'efficacité énergétique des navires.
- c) Technologie portable et énergie du soldat.

Statut et recommandations Le RTG a accompli toutes les tâches décrites dans l'approche ci-dessus et recommande que les informations contenues dans l'OEIDB soient mises à la disposition de représentants appropriés des gouvernements des pays membres, alliés et partenaires de l'OTAN via une page Internet, à l'aide de l'application R Shiny (servant de tableau de bord et d'interface graphique de la page Internet), et que l'OEIDB et la page Internet résident sur un serveur situé au Centre d'excellence pour la sécurité énergétique de l'OTAN, à Vilnius, en Lituanie. Le principal travail du RTG SAS-119 de l'OTAN s'achève par ces recommandations. Les analystes des États-Unis continueront de s'impliquer et de travailler avec les interlocuteurs du Centre d'excellence pour la sécurité énergétique de l'OTAN, à Vilnius, en Lituanie, afin de mettre à jour la page Internet de l'OEIDB.

ENERGY AND DEFENCE: REDUCING DEPENDENCIES AND VULNERABILITIES – ENHANCING EFFICIENCY

1.0 INTRODUCTION

1.1 Purpose / Overarching Objective

The overarching objective of this activity has been to contribute to military aspects of energy security within the NATO Alliance and partner nations, by examining several key areas of interest, by sharing information and approaches to enhancing energy efficiency, and by promoting best practices amongst NATO members with respect to enhancing energy efficiency in those key areas. The NATO Centre of Excellence for Energy Security and Allied Command Transformation are integrated into this research effort. See Technical Activity Proposal (TAP), Annex A [1].

1.2 Problem Statement

By being a large consumer of energy, especially fossil fuels, the armed forces of most Allied nations are highly dependent upon imports from countries that are located in unstable regions beyond Allied influence. Furthermore, the amount of oil used per soldier continues to increase, hence impacting operational effectiveness by limiting range, speed and freedom of movement (see Ref. [1], Annex A).

1.3 Background

Developments during the latest decades have put what is often the non-military issue of energy on the NATO security agenda. Frequent terrorist attacks on NATO fuel convoys in Afghanistan and Pakistan have led to an increased awareness within the Alliance of the crucial role of supply in missions which involve long distances and sustained presence. Within its present energy security agenda, NATO's focus is on three major areas:

- 1) Raising strategic awareness of energy developments with security implications;
- 2) Contributing to the protection of critical energy infrastructure; and
- 3) Enhancing energy efficiency in the military (see Ref. [1], Annex A).

The NATO Science and Technology Organization (STO) Science and Technology Board (STB) approved the TAP which established the Systems Analysis and Studies 119 (SAS-119) Research Task Group (RTG) in May, 2015. This activity supports NATO's energy security agenda by focusing primarily on the third major area – specifically enhancing energy efficiency through applied technical solutions concentrating on the crucial role of Operational Energy (OE) (see Ref. [1], Annex A).

Initiatives that focus on energy efficiency are already conducted within NATO. Two examples are Smart Energy Team (SENT) and Innovative Energy Solution for Military Applications (IESMA). An important aspect in this activity will be to make the most out of limited resources, thus building on existing work rather than duplicating what has already been done, within NATO as well as within the participating nations' Ministries of Defence (MoD) (see Ref. [1], Annex A).

1.4 SAS-119 RTG Objectives

SAS-119 RTG focuses on reducing dependencies on energy resources outside of the Alliance by enhancing energy efficiency through applied technical solutions, focusing on operational energy. The main objectives of SAS-119 RTG are to:

- a) Gather information on successfully implemented OE initiatives;
- b) Develop a methodology for assessing the relative goodness of those initiatives enabling those interested in implementing OE initiatives in their own military to determine which ones were most pertinent or desirable based on their own requirements; and to
- c) Share that information with the NATO member nations, allies and partners, and make it accessible to them for future use and reference.

Accomplishing these objectives will result in an additional resource for the MoD of the NATO member nations, allies and partners to use in their selection and decision making process for choosing new OE initiatives to implement in their own nations and helping them to realize reduced fuel consumption, the accompanying reduction in fuel expenses as well as decreased operational risk.

The final objective of the RTG is to produce a Technical Report deliverable by early September 2019. This RTG Technical Report will also provide input to the Emerging Security Challenges division at NATO HQ in order to support their work on energy security.

2.0 APPROACH, SCOPE AND TASKS

2.1 Approach

The SAS-119 RTG approached this project as a simple and basic research project. Our primary task was to gather and collect information and data on successfully implemented OE initiatives. Our focus was on OE initiatives implemented primarily at the operational and tactical levels, thus dealing with more hands-on issues related to energy efficiency such as applied technology and behavioral change in energy consumption.

The RTG team relied on quantitative research from credible sources to include Subject Matter Expert (SME) interviews and/or surveys within the member nations' MoD to determine projects already sponsored/initiated/conducted throughout the Alliance and government owned or hosted internet websites that contain pertinent data and information With Respect To (WRT) the individual OE initiatives identified by the RTG.

The information and data that the RTG collected has been used to build a searchable OE Initiatives Data Base (OEIDB). The RTG developed metrics used to assess the relative "goodness" of similar initiatives in the OEIDB so that a relative comparison can be performed and "best fit" options identified. The final step was for the RTG to explore options and make recommendations for an appropriate home for this OEIDB including recommendations for an appropriate software platform and dashboard for containing and querying the OEIDB, and an appropriate organization to maintain the server and manage access to the OEIDB.

2.2 Scope

As indicated in Section 2.1 above, the focus of the RTG is primarily on OE initiatives successfully implemented (or demonstrated) at operational and tactical levels. This research effort is further scoped to the following three areas of interest. These areas of interest represent a subset of the areas of interest provided to the RTG in the TAP guidance document:

- a) Energy efficient base camps;
- b) Energy efficiency improvements for ships; and
- c) Soldier wearable technology and Soldier power.

2.3 Tasks

The first and primary task was an information and data collection exercise to collect input data, mostly but not only from MoD in the participating countries. The goal was to collect information on each nation's applications of OE related technologies that have been successfully fielded that could potentially be beneficial to the NATO OE community. The RTG relied on both qualitative and quantitative research.

For an initiative to be included in the OEIDB, the characteristics of the initiative had to be collected. This included descriptive information that was used to categorize the initiative as well as quantitative data that was used to assess the relative goodness of the initiative. Examples of this data include:

- a) Cost (per ship, or per item of equipment, or per soldier).
- b) Amount of fuel saved per hour of operation.
- c) Estimated total annual cost savings realized by the initiative.
- d) Estimated total annual fuel savings for the initiative.

The information and data items collected for each OE initiative were consolidated into an OE Initiatives Inventory Spreadsheet. The members of the SAS-119 RTG placed the information and data they collected into a copy of this spreadsheet and submitted the spreadsheet to the OEIDB manager, a U.S. analyst located at The Research and Analysis Center (TRAC) located at Fort Lee, VA, USA. The OEIDB manager reviewed each submission for completeness, content, and format, suggested edits, and helped the individual SAS-119 RTG team member finalize their entry prior to inclusion into the OEIDB. Each member of the SAS-119 RTG was responsible for collecting information and data on the OE initiatives from their own nation.

In parallel with the data collection effort, the RTG developed a set of suitable metrics for each category of initiatives to use in assessing their relative goodness. Details about the metrics along with the methodology used to develop relative scores for the initiatives are provided in the next section. It is important to note that initiatives are compared within a category and not across categories.

The next task was to either recommend an existing platform to use for sharing information among the NATO member nations, allies and partners or develop a new platform to improve the exchange of best practices. It is important to note that one of the goals of the RTG was to avoid duplication of effort and consider whether an existing platform could be utilized rather than establishing a new one.

The final task was to prepare and submit a Technical Report by early September 2019.

3.0 METHODOLOGY FOR DATA VISUALIZATION

3.1 General Description

The OEIDB contains initiatives for base camps, ships, and soldier power that focus on reducing energy/fuel demand, soldier risk, and soldier burden, while increasing operational endurance, responsiveness and efficiency. It consists of a database created in Excel and overlaid with a user interface created in R Shiny, a free, open source statistical and graphics software package. The R Shiny user interface allows users to select one of three tabs:

- a) How to Use OEIDB;
- b) Factsheets; or
- c) Initiative Scoring.

The first tab displays directions on how to use the OEIDB visualization tool (or dashboard). The Factsheet tab allows the user to select an individual initiative by type (base camp, ship, or soldier power), and displays the associated Measures Of Merit (MOM) and weights as they relate to other initiatives of the same type, along with a picture, a country of origin, a source, and a description. An example of a factsheet is shown Figure 1 below.

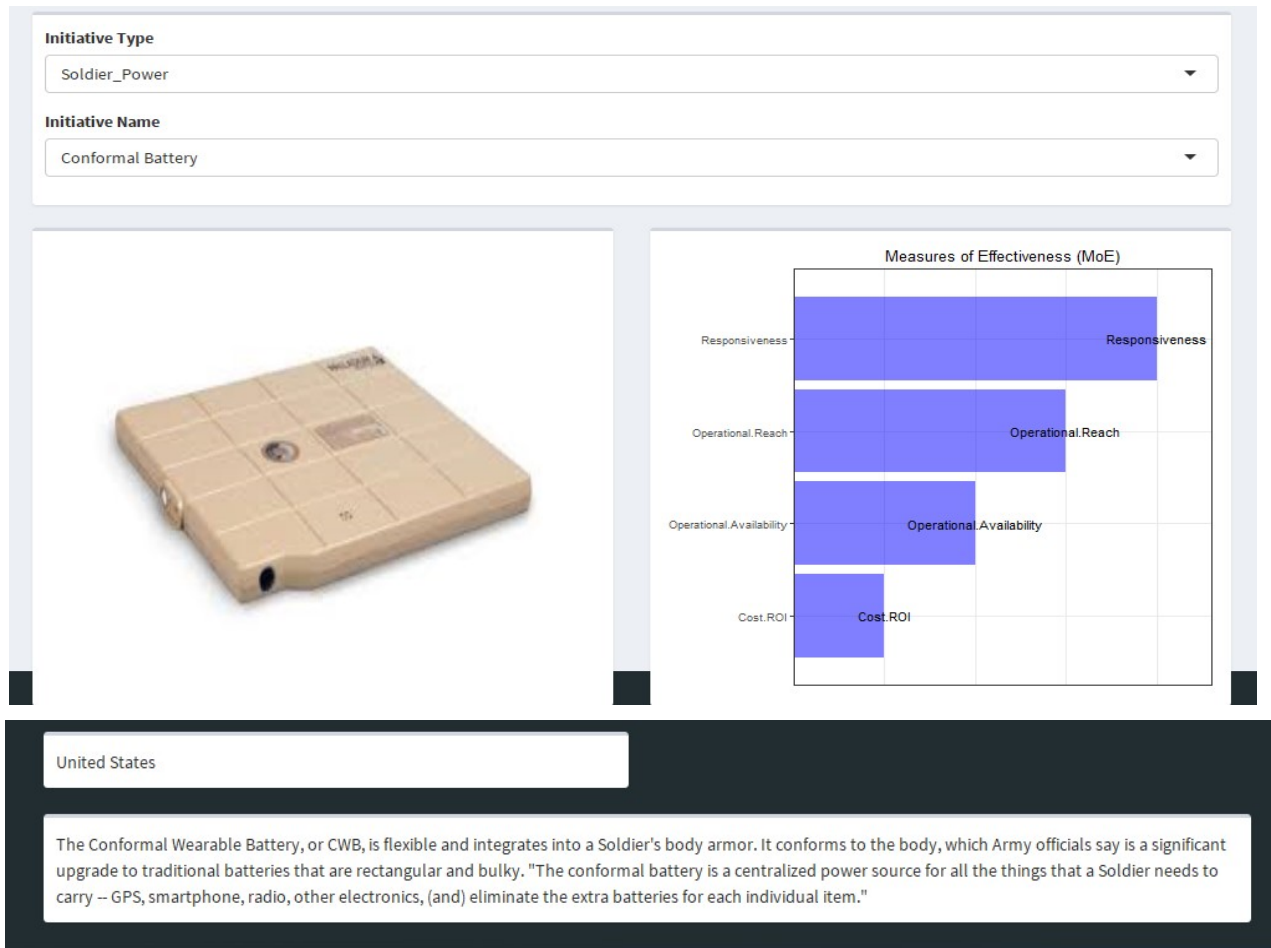


Figure 1: OEIDB Factsheet.

All of the fields on the Factsheet tab are read into the R Shiny application from the Excel workbook file which consists of three spreadsheets, one for each initiative type. The database administrator converts the spreadsheets to Comma-Separated Values (CSV) files that are compatible with the R Shiny application. This process makes sure there are no formulas present and ensures R Shiny can read the files and displays the appropriate fields properly and according to what the user selected. R Shiny also reads in the images and displays them on the factsheets it generates.

The Initiative Scoring tab allows users to select the type of initiative they are interested in and displays a list of all initiatives of that type, rank ordered initially by default settings. The default setting assumes all MOM are equally important and have the same weight. The users can then adjust the weights of each MOM using a slider, adjusting the value from one to five, in accordance with their own estimation of the relative importance of each. This will cause the dashboard to automatically and instantaneously recalculate the relative scoring and reorder the initiatives accordingly.

3.2 Scoring Methodology for Base Camp Initiatives

The **Base Camps** spreadsheet currently contains more than 40 initiatives from six different countries. It contains the initiative name, description, country of origin, and source along with other fields, including six MOM for each initiative, along with data associated with each of the MOM. The MOM for Base Camp initiatives are shown below along with the associated types of data for each:

- Operational Endurance – demand reduction percentage; amount of time the fuel tank lasts (hours).
- Logistics Burden – fuel consumption rate (litres/hour).
- Power Generation – tank storage capacity (litres); peak production/energy output (kW).
- Transportability – weight (kg), volume (m³).
- Personnel Risk – health risk (decibels or amount of light emission); convoy risk (soldier exposure hours).
- Interoperability – microgrid compatibility (Y/N) ; multinational compatibility (Y/N).

To quantify these measures analysts researched each initiative and gathered data associated with each MOM. Data was converted to the appropriate unit of measure (litre, kg, m³, etc.) as necessary. In cases where exact data was not available, data from a similar item was surrogated. In order to determine Operational Endurance and Personnel Risk, two data elements had to be calculated: amount of time the fuel tank lasts and convoy risk. The amount of time the fuel tank lasts was calculated by dividing the tank storage capacity by the fuel consumption rate. A Modeling and Simulation (M&S) scenario was used to determine data elements needed to calculate Personnel Risk. Convoy risk, one of the components of the Personnel Risk MOM, was based on the number of hours soldiers spent in resupply operations for the initiative. This was calculated by:

- 1) Determining the fuel truck miles attributable to the initiative;
- 2) The average speed of the fuel truck that was used to resupply that initiative;
- 3) Dividing the miles attributable by the average speed resulted in the hours of exposure.

Data elements were then normalized and rescaled to have values between zero and one. In many cases the higher the value, the better. For example, the greater the tank size capacity, peak production/energy output, demand reduction, and time to resupply, the better. However, in other cases, less is better. For example, lower fuel consumption, weight, volume, health risk, and convoy risk are preferred. For comparison purposes, when lower numbers are preferred, the rescaled values have to be inverted so as to reflect that a higher value is better. The same formula can be used, and the value inverted simply by subtracting the output of the formula below from one. Stated more simply, in cases where a larger number was more desirable, the formula below was used. In cases where a lower number was more desirable, one minus the formula below was used.

$$x_{new} = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (1)$$

The rescaled values (or average of the rescaled values if there was more than one), were used to create the score for each MOM. Note that for Interoperability, a 0.5 was assigned to most alternatives because while they could be used internationally and attached to a microgrid, some modification would be likely be necessary. Items that did not require modification (like tents) were assigned a value of 1.

3.3 Scoring Methodology for Ship Initiatives

The **Ships** spreadsheet currently contains 12 initiatives and includes four MOM, which are shown below:

- Operational Reach – speed (knots), efficiency (litres / km / displaced volume), and range (km).
- Operational Availability – time on station (hours).
- Responsiveness – speed (knots).
- Cost/Return on Investment – cost (low, medium, high), fuel saved (barrels/year).

Exact quantitative data was often not available for ships, so analysts relied on qualitative descriptions compared to a baseline. Cost was determined to be either ‘high, medium or low’. All other MOM were determined to be an ‘increase, no change, or decrease’, based on descriptions found indicating the change in the ship characteristics before and after the initiative was in place. MOM involving speed, efficiency, range and responsiveness, were set to 0.5 for no change, or 0.6 for an increase. Criteria involving frequency of maintenance was set to 0.5 for no change, or 0.6 for a decrease in frequency of maintenance. Fuel saved was set to 0.5, plus the percent saved / 100, or 0.6 if there were fuel savings but the amount saved was unknown. The rescaled values (or average of the rescaled values if there was more than one), were used to create the score for each MOM.

3.4 Scoring Methodology for Soldier Power Initiatives

The **Soldier Power** spreadsheet currently contains 12 initiatives and includes seven MOM which are shown below, along with their associated data:

- Soldier Burden – weight (kg), volume (cm³).
- Operational Endurance – storage capacity (Wh).
- Detectability by Threat – light signature (low, medium, high), noise (decibels, low medium, high).
- Reliability – weather limitations.
- AC/DC Voltage – voltage.
- Density – power/capacity (W), weight (kg).
- Cost – low, medium, high.

Weather limitations were defined by range of temperature under which the initiative could operate, and density was power or capacity divided by weight. When exact metrics could not be determined, such as for light signature, noise, or cost, a scale (i.e., low, medium, high) was used instead. The fields containing numeric data (weight, volume, storage capacity, AC/DC voltage, density) were then rescaled to values between zero and one as described previously for base camps. The weather limitations data element was rescaled by subtracting the lowest temperature from the highest temperature and dividing by 100. Light signature, noise and cost were assigned a value of 0.5, or 0.7 for medium or low respectively. (Lower light emission, noise, and cost are better and therefore get higher scores.) The values for the MOM were determined using these rescaled values (or average of the rescaled values if there was more than one).

4.0 BASE CAMP INITIATIVES

This section provides descriptive information about each of the initiatives in the Base Camp category along with a picture of the piece or pieces of equipment. This category is by far the largest category for which the RTG was able to collect information / data. There are currently 41 Base Camp OE initiatives represented in the OEIDB. These have been grouped together into eight categories for initiatives that are similar or serve

a common purpose. Base camps can vary greatly in size as well as the length of time they may be in use. The appropriateness or applicability of an individual initiative may depend on the size of the basecamp it will serve and the duration of its use. Generally, the larger the base camp and the longer it will be used, the greater the opportunity to realize significant savings through the employment of energy consumption reducing equipment and alternative energy sources.

4.1. Environmental Control Units (ECU)

The Improved Environmental Control Unit (IECU) (Figure 2) is ruggedized, reduces weight, and increases reliability and form, fit and function of MIL-STD ECUs. The IECU uses R-410A refrigerant. R-410A replaces R-22, which is being phased out in the U.S. R-410A is the preferred refrigerant in Japan, Europe and the U.S. The country of origin is the United States. IECUs are available in 9K, 18K, 36K, and 60K British Thermal Units per hour (BTUH) [2], [3].



Figure 2: Improved Environmental Control Unit (IECU).

4.2 Generators

The NATO database includes the third generation Advanced Medium Mobile Power Source (AMMPS) generators. The country of origin for all the generators shown here is the United States [2], [3].

4.2.1 Advanced Medium Mobile Power Source (AMMPS)

AMMPS (Figure 3) replaces the second generation 5 kW – 60 kW medium Tactical Quiet Generators (TQG). Across the fleet, AMMPS improves fuel efficiency by 21%, reduces size and weight by 10%, and increases reliability by 90% [2], [3].

4.2.2 Large Advanced Mobile Power Sources (LAMPS)

LAMPS (Figure 4) will be the third generation of Large Tactical Electric Power 100/200 kW generator sets. The LAMPS generator sets are at the end of the tactical electric power spectrum and will come in two configurations, skid and trailer-mounted [2], [3], [4].



Figure 3: Advanced Medium Mobile Power Sources.



Figure 4: Large Advanced Mobile Power Sources (AMMPS).

4.2.3 Deployable Power Generation and Distribution System (DPGDS)

DPGDS (Figure 5) is an 840 kW skid mounted generator. It is configurable for single unit operation or up to four units operating as a mini-grid power plant, providing load-sensing automatic operation controlled by laptop computer. It is also available with semi-trailer mobility package for movement at highway speeds (55 mph) [2].



Figure 5: Deployable Power Generation and Distribution System (DPGDS).

4.3 Power

The NATO database includes the Deployable Power Module from the Netherlands; Electrical Distribution and Feeder Systems from the United States; Hybrid Power System from Greece; Hybrid Power Emissions Reduction from the United Kingdom; LED lighting from Germany; Solar Photovoltaic Cells from Germany and the United States; and a Solar Power Plant from Austria [5].

4.3.1 Deployable Power Module

The Deployable Power Module (Figure 6) is the heart of a micro grid providing electricity to a part of the NATO owned camp installed by NATO Support and Procurement Agency (NSPA). The Power Module is based on an innovative concept of power management, coupled with hybrid energy sources and batteries. Production: 80 kW diesel generator and 20 kW by 120 m² solar power field. Battery storage: 136 kWh [5], [6].



Figure 6: Deployable Power Module.

4.3.2 Electrical Distribution System

The Power Distribution Illumination System, Electrical (PDISE) (Figure 7) is a family of power feeder, distribution and illumination equipment which transmits electrical power between power generating and power using sources. Some PDISE supplements currently fielded illumination and adds distribution capabilities. PDISE distributes power from a larger-size generator to provide 24-hour operation to a location versus the utilization of eight or 10 smaller generators. PDISE takes power from the generator and breaks it down into different amperage levels. The system is able to provide different usage requirements from one generator unit. PDISE comes in two sizes of feeder boxes (100 and 200 Amps) and two sizes of distribution boxes (40 [three phase] and 60 [single phase] Amps), each with connecting cables, and a utility assembly of extension cords, branch circuits and lighting equipment [2], [7], [8].



Figure 7: Electrical Distribution System.

4.3.3 LED Lighting

LED lighting (Figure 8) replaces conventional illumination. The Setolite brand of lighting equipment is for indoor or outdoor and fixed or mobile usage. An area that typically uses of 22 kW will use 4.5 kW. Germany is the country of origin of the Setolite brand [9], [10].



Figure 8: LED Lighting.

4.3.4 Hybrid Electrical Power System (HEPS)

The Mobile Tactical Hybrid Power Stations combine conventional (e.g., generators) and renewable energy sources with modern energy storage systems (Figure 9). The family of products can add mobility, energy safety and increased availability to almost any system powered by electricity, providing at the same time a significantly lower operational cost. Intracom Defense Electronics from Greece develops and manufactures advanced power stations for small to medium power installations [5], [11].

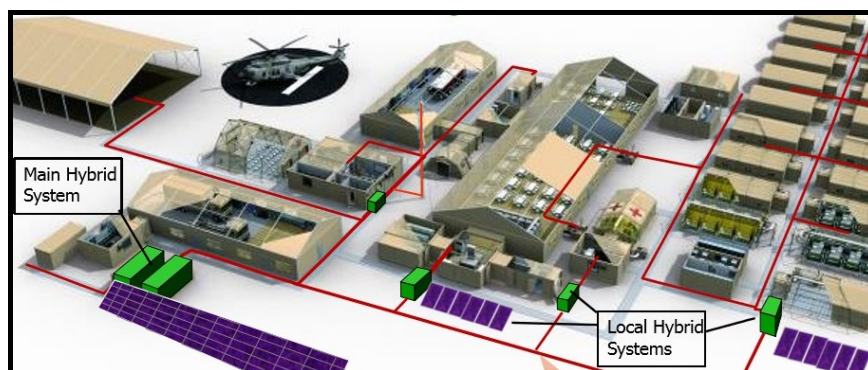


Figure 9: Hybrid Electrical Power System (HEPS).

4.3.5 Hybrid Power Emissions Reduction – Fuel Savings Technology (HyPER-FST)

In the majority of climatic and economic conditions around the world, the optimum Return-on-Investment (ROI) for off-grid energy can be achieved from a hybrid power system. Renovagen's Hybrid Power Emissions Reduction – Fuel Savings Technology (HyPER-FST) (Figure 10), integrated into Rapid Roll systems, delivers fuel savings by leveraging auto start-stop control of a diesel generator to reduce the number of running hours – and most importantly runs the generator at its most efficient operating point when it is required. These work with existing generators. The technology also facilitates the easy supplementation of

hybrid power with solar energy – from 0 % solar to 99 % – depending on location and weather conditions. The presence of the generator eliminates “weather anxiety” and guarantees that backup power will always be available. Typically fuel savings of 50 % to 95 % can be realized in the HyPER-FST solar-battery-diesel hybrid. The highly mobile Roll-Array solar power plant is connected to micro grids or island solutions to provide additional power when needed. The motorised photovoltaic (PV) Roll-Array rolls up into a trailer in 5 minutes [5], [12].



Figure 10: Hybrid Power Emissions Reduction – Fuel Savings Technology (HyPER-FST).

4.3.6 Solar Photovoltaic (PV)-Rigid Cells

Photovoltaics (Figure 11) is a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons. PV cells produce DC output that can be converted to AC using grid-tied inverters (single or three phase) for easy and safe integration into a power network. A range of sizes from highly modular, single panel systems to multi-acre farms (550 MW) can be installed based on the same core technology components. A single module is defined as an array of eight panels with a single phase inverter to connect them to the grid [2], [13].

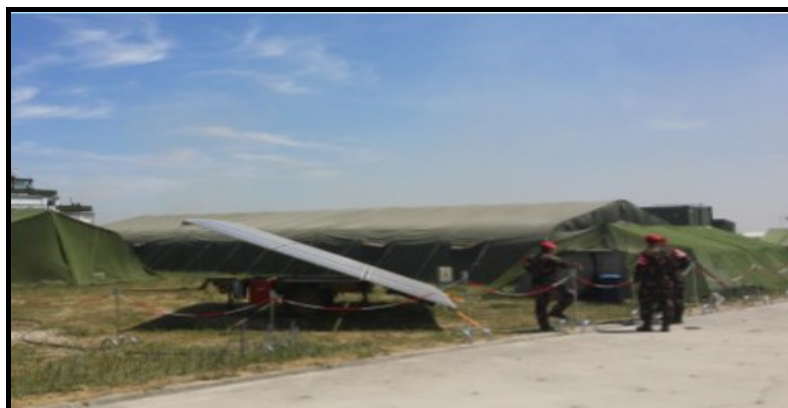


Figure 11: Solar Photovoltaic (PV) – Rigid Cells.

4.3.7 Solar Power Plant

The Smartflower company from Austria runs its solar power plant REMULES (REnewable Mobile Ultra Light Energy System) as a stand-alone operation or connected to various energy storage systems and micro grids (Figure 12). Micro grids using hybrid power (diesel and renewable sources), battery storage and an energy management can reduce the fuel consumption instantly by 40 – 50 % [5], [14].



Figure 12: Solar Power Plant.

4.4 Space Heater Convective (SHC)

The NATO SAS OEIDB includes the 35K and 60K BTU space heaters from the U.S.

The SHC (Figure 13) is a 35K BTU thermoelectric (TE) heater that provides forced hot air circulation in military tentage without the need for an external power supply and eliminates the need for a field generator to operate the heater. The SHC is the first of its kind to successfully integrate TE and combustion into a fieldable heater that delivers clean, breathable heat to military tentage and shelters. The TE heater generates its own electrical power (approximately 200 W) through the use of thermoelectric modules located in the combustion chamber. These modules convert waste heat into electrical energy, which is used to power the blowers, pumps, ignition system, safety system and control devices required in the operation of the heater. The heater provides a 60% increase in combustion efficiency over currently fielded non-powered heaters and provides much cleaner combustion of diesel fuel, translating to significantly reduced fuel costs and maintenance requirements.



Figure 13: Space Heater Convective.

The SHC 60K is a 60K BTU TE heater that increases the heat output of the SHC from 35,000 to ~60,000 BTU/hr to expand its application for heating larger areas. Similar to the SHC, the SHC 60K operates outside the tent/shelter and provides forced air heating which supplies better heat distribution than radiant type heaters, frees up floor space and eliminates the need for a fire guard and requires no external generator [2], [15], [16].

4.5 Structure

The OEIDB includes Insulated Tents DEFSHELL from Italy, and SCHALL from Germany; a micro grid from the U.S.; and Smart Energy Efficient Deployable Shelters (SEEDS) from the U.S.

4.5.1 Insulated Tent-DEFSHELL

The insulated tent by DEFSHELL (Figure 14) are carbon hybrid, thermocanvas portable structures. Aluminium profiles reinforced with special fibers reduce both the weight and volume of the structure material. The thermocanvas membrane increases insulation and comfort by reducing the transmission of radiated heat. The silver color treatment on the surface, increases environmental comfort and brightness avoiding at the same time the unpleasant PVC smells [5], [17].



Figure 14: DEFSHELL Insulated Tent.

4.5.2 Insulated Tent – Schall

The insulated tent by Schall (Figure 15) is an ALU-framed or inflatable highly insulated tent with solar power panels providing shelter for the fuel laboratory at the Bulk Fuel Installation. It can be connected to the micro grid [5], [18].

4.5.3 Microgrid

Microgrid system (Figure 16) monitors camp power demand and automatically turns on and shuts down generators based upon load demand. The microgrid can also share loading among generators, distribute power loads and limit load shedding [3].



Figure 15: SCHALL Insulated Tent.

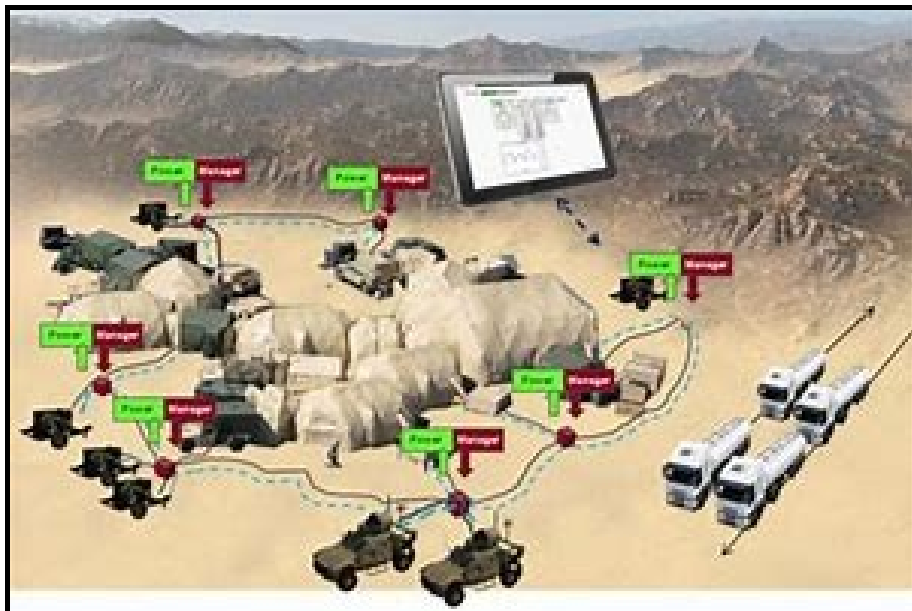


Figure 16: Microgrid.

4.5.4 Smart Energy Efficient Deployable Shelters (SEEDS)

SEEDS (Figure 17) maximizes the thermal efficiency of expeditionary shelters by improving the effective thermal resistance of each of the shelter's envelope layers. As a result, the energy needed by the ECUs in cooling and heating the shelters is reduced by up to 70%. The main goal of this shelter is to maximize forward operating bases' energy efficiency to allow the bases to reach near energy self-sufficiency. The shelter is the next generation energy reducing technology for deployed soft-walled shelters which will greatly reduce energy consumption. There is no new training required since the new technology will already be incorporated into the manufacturing process of the current shelter system [2], [19].

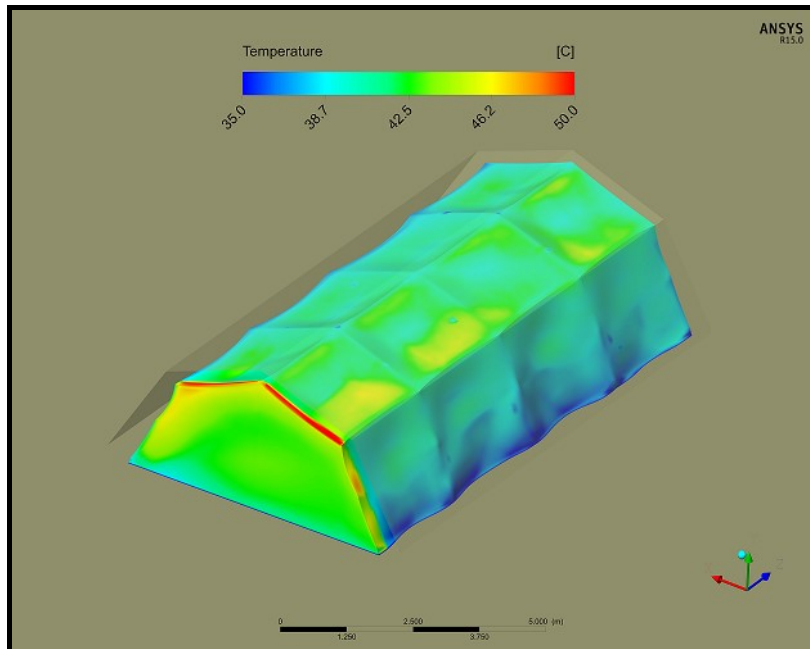


Figure 17: Smart Energy Efficient Deployable Shelters (SEEDS).

4.6 Thermal Management

The OEIDB includes the Army Hot Water Heater from the U.S. and a mobile air conditioning with energy efficient heat exchange from Germany.

4.6.1 Army Water Heater (AWH)

The Army Water Heater (Figure 18) is a fuel fired, skid mounted water heater suitable for military transport. Burner components and heat exchanger have been selected for low maintenance and long life, and the modular design provides short Mean Time To Repair (MTTR). The AWH has an improved service life and performance including hot water output and combustion quality [2], [20].

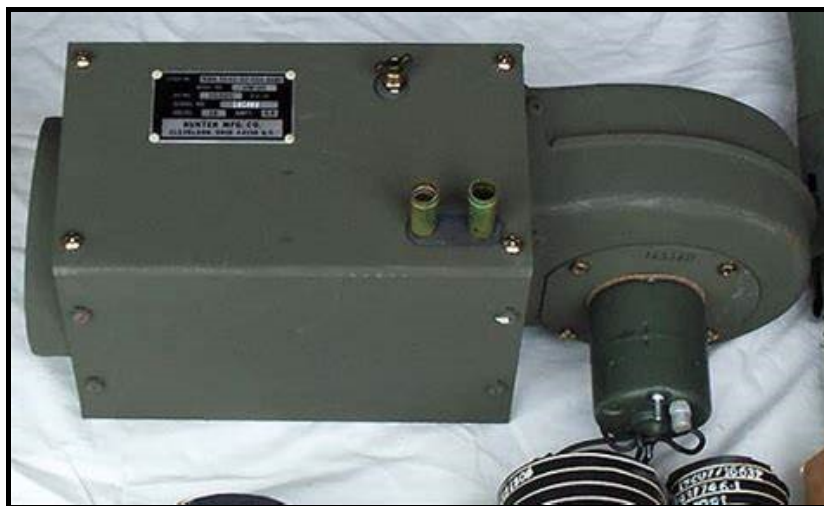


Figure 18: Army Water Heater (AWH).

4.6.2 Mobile Air Conditioning Unit

A mobile air conditioning unit (Figure 19) from Germany uses an energy efficient heat pump/heat exchange technology to cool tents. Consumption: 5 kW. Cooling/heating capacity: 15 kW [5].



Figure 19: Mobile Air Conditioning Unit.

4.7 Waste

4.7.1 Shower Water Reuse System (SWRS)

SWRS (Figure 20) is a rapidly deployable, mobile, fully self-contained system capable of recovering up to 9K gal/day of shower gray water and filters it to reuse quality for shower applications. The wastewater is first filtered through a 15 micron pre-filter and two 0.2 micron microfilters, followed by three 8-inch saltwater reverse osmosis elements. This water is then filtered further through two carbon filters, exposed to bacteria-killing UV light, and finally shocked with calcium hypochlorite to prevent coliform growth. The system has a 75 percent recovery rate. The SWRS is housed in an 8 ft x 8 ft x 6.5 ft ISO Container certified TRICON which weighs less than 10,000 pounds. SWRS will filter approximately 12,000 gallons of shower and sink waste water per day with a peak flow rate of 40 gallons per minute [2], [21], [22].

4.7.2 Deployable Waste-to-Energy Conversion (DWEK)

The DWEK (Figure 21) represents a cost effective and efficient system especially designed for expeditionary waste disposal. Combined with the optional Heat Energy Recovery System (HERS), the DWEK produces a net energy benefit in the form of potable hot water for showers, kitchens, or laundry [23].

4.8 Water

Water initiatives in the OEIDB include the Expeditionary Water Packaging System from the U.S., a Mobile Water Purification System from Germany, a Tactical Water Distribution Equipment System (TWDS), a Tactical Water Purification System (TWPS), and Water from Air from the U.S.



Figure 20: Shower Water Reuse System (SWRS).



Figure 21: Deployable Waste-to-Energy Conversion (DWEK).

4.8.1 Expeditionary Water Packaging System (EWPS)

The Expeditionary Water Packaging System (EWPS) (Figure 22) is a rugged, deployable, highly compact water bottling capability. Housed in a modified 20-foot ISO Container, the system can be transported to a remote location and connected to any approved, pure water source. EWPS reduces the distribution footprint for bottled water and the casualties associated with line-haul distribution. (50% of convoy trucks were used to transport water bottles in Iraq.) It provides inherent safety and health benefits by reducing Soldier contamination at bulk system fill points and minimizes the cost associated with procuring and transporting bottled water. The EWPS produces 1300 bottles per hour and uses less than 60 kW. The system is ideally suited for use in austere military contingency base camps and disaster relief. Bottles can be stored for up to 12 months [2], [24], [25], [26].



Figure 22: Expeditionary Water Packaging System (EWPS).

4.8.2 Mobile Water Purification System

The Mobile Water Purification System (Figure 23) uses adsorptive cartridges for ultrafiltration and removal of particulate contamination. It is lightweight and uses 1 kW to produce 400 l/h of purified water. Optional UV disinfection and Chlorination are available. Concepts of Operation adaptation to unit size, energy consumption and mobility are available [5].



Figure 23: Mobile Water Purification System.

4.8.3 Tactical Water Distribution Equipment System (TWDS)

Tactical Water Distribution Equipment System (TWDS), Figure 24. All four models of the TWDS perform the same function. The TWDS receives water from large storage and distribution units, water purification units, host nation support, or additional TWDS. The TWDS transports this water to small distribution points, additional TWDS, or large storage and distribution units. The TWDS is capable of transporting up to 720K gal of water in a 24 hour period. The TWDS is not intended for use with brackish or contaminated water or at temperatures below 32 °F (0 °C). The TWDS is used to transport potable water across level terrain for distances up to 10 miles. Five or six pumping assemblies are used to transport water from a source, desalination units, wells, or large storage and distribution units, to two 20,000 gallon storage assemblies, additional TWDS units, or larger storage and distribution units. The water stored in the two 20,000 gallon pillow tanks can be supplied to large storage or distribution units or can be chlorinated and dispensed to personnel through two distribution points. It can transport water at 600 GPM across level terrain and can transport 720,000 gallons of water within a 24 hour period. It can be deployed and operational within 48 hours [2], [27], [28], [29].



Figure 24: Tactical Water Distribution Equipment System (TWDS).

4.8.4 Tactical Water Purification System (TWPS)

The TWPS (Figure 25) is a complete water purification system that consists of feed water pump, hoses, ROWPU elements, pre-filter, high pressure pump, 60 kW TQG generator, 15K gal water storage and distribution system, and control panel. Each TWPS will replace 2 – 600 ROWPU which reduces manpower requirements and the logistics footprint [2], [30].

4.8.5 Water from Air

Water from Air (Figure 26) provides the next generation of water production and distribution capabilities through mobile water from air generation/storage. The effort does this by generating water from atmospheric humidity using absorption/desorption desiccant technology, energy recovery and condensation [2], [15], [16].



Figure 25: Tactical Water Purification System (TWPS).



Figure 26: Water from Air.

5.0 SOLDIER POWER INITIATIVES

The modern soldier has been equipped with technologically advanced equipment to enhance his ability to maneuver on the battle field, sense the enemy, and communicate at the tactical and operational levels. All of these technologically advanced pieces of equipment require electrical power. As the name of this category,

Soldier Power, implies, the focus is on equipment that provides the individual soldier or small group of soldiers with the power they need to keep their electronic devices operating. This section provides descriptive information about the Soldier Power initiatives that are contained in the OEIDB along with a picture of the piece or pieces of equipment. The initiatives include batteries, battery chargers, generators and energy collecting systems that capture energy from alternative sources, including the soldier himself.

5.1 Battery

The OEIDB contains two batteries from the United States: the conformal battery and the hybrid battery.

5.1.1 Conformal Battery

The Conformal Wearable Battery, or CWB, (Figure 27) is flexible and integrates into a Soldier's body armor. It conforms to the body, which Army officials say is a significant upgrade to traditional batteries that are rectangular and bulky. "The conformal battery is a centralized power source for all the things that a Soldier needs to carry – GPS, smartphone, radio, other electronics, (and) eliminate the extra batteries for each individual item" [31].



Figure 27: Conformal Battery.

5.1.2 Hybrid Battery

The BA-5790 Lithium Carbon Monofluoride (Li-CFx)/Lithium Manganese Dioxide (Li-MnO₂) hybrid battery (Figure 28) provides twice the energy of the non-rechargeable military standard BA-5590/U Lithium Sulfur Dioxide battery in the same size and weight. This high energy density non-rechargeable battery allows the user to carry fewer batteries to complete the mission, therefore increasing Soldier's mobility and lethality [32].

5.2 Charger

The OEIDB contains three chargers: the SFC Power Manager and the Portable Fuel Cell Power System from Germany, and the Solar Portable Alternate Communications Energy System (SPACES) from the United States.

5.2.1 SFC Power Manager 3G

The SFC Power Manager 3G (Figure 29) charges batteries efficiently and provides power to equipment in the field. Intelligent and configurable power management reduces the overall weight of the power system significantly while increasing the efficiency of the operation at the same time [33], [34].



Figure 28: Hybrid Battery.



Figure 29: SFC Power Manager 3G.

5.2.2 Solar Portable Alternate Communications Energy System (SPACES)

The Solar Portable Alternate Communications Energy System (SPACES) (Figure 30), is a portable lightweight battery charger and DC power distribution system. It can use various sources of DC input power, including renewable solar energy [35], [36].

5.2.3 Portable Fuel Cell Power System

JENNY 600S (Figure 31) is the portable fuel cell from SFC. Efficient, compact and lightweight. JENNY 600S charges batteries without any user action [33].



Figure 30: Solar Portable Alternate Communications Energy System (SPACES).



Figure 31: Portable Fuel Cell Power System.

5.3 Energy Harvester

The OEIDB contains two energy harvesters from the U.S.: The Energy Harvesting Assault Pack and the Mechanical Motion Rectifier.

5.3.1 Energy Harvesting Assault Pack (EHAP)

The Energy Harvesting Assault Pack, or EHAP (Figure 32), is a system that converts vertical kinetic energy from a Soldier's walking and running into electrical energy using a double-frame load suspension system. The EHAP enables longer duration missions without battery resupply at decreased logistical burden [37], [38].



Figure 32: Energy Harvesting Assault Pack (EHAP).

5.3.2 Mechanical Motion Rectifier

The MMR (Figure 33) is a tube-like energy harvester that generates electricity during walking. It is embedded into a backpack to provide continuous power to electronics. (7W when walking at 5.5 km/h; 15 W when driving 15 mph) [39].

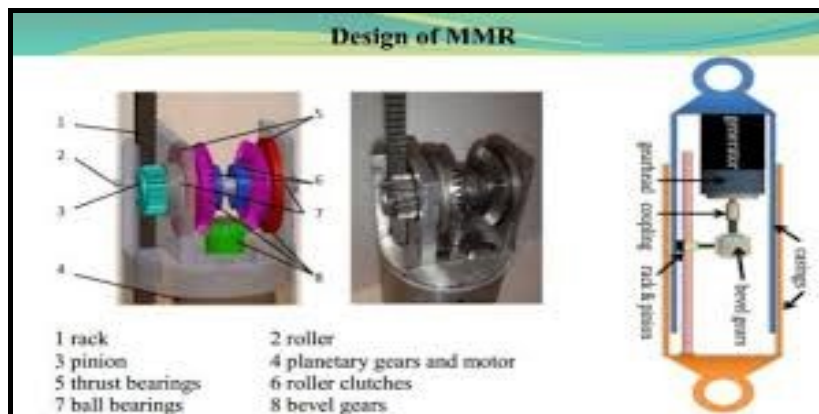


Figure 33: Mechanical Motion Rectifier.

5.4 Generator

The 1 kW Multi-fuel Generator (Figure 34) is an alternative energy hybrid generator that provides intelligent, tactical and convenient squad-level power for Tier 1 and Tier 2 environments to support military forward operating bases and expeditionary missions. It converts liquid fuels and compressed fuels into continuous streams of AC/DC power output. The Multi-fuel Generator operates on liquid fuel and compressed fuel configurations such as: kerosene, propane, gasoline, but also operates on heavy fuels such as DF-2 and JP-8 [40].



Figure 34: 1 kW Multi-Fuel Generator.

5.5 Power

5.5.1 120 Watt Solar Panel

The 120 Watt flexible solar panel (Figure 35) provides the capability to the individual Soldier or Unit of recharging batteries in a remote tactical environment. The ruggedized solar panel (able to sustain bullet holes and still function) is weather resistant, low-light capable and requires no sun soaking. It reduces the Soldier load by limiting the need for multiple batteries, therefore easing the logistical resupply. The solar panel fits neatly in the rucksack and deploys in seconds [41], [42].

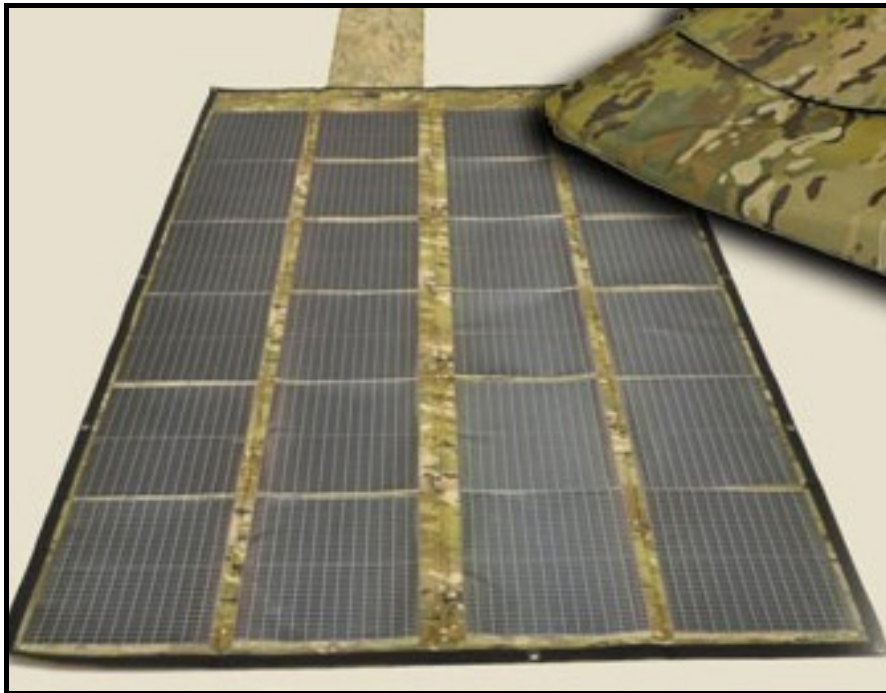


Figure 35: 120 Watt Solar Panel.

5.5.2 BANTAM Power Scavenger

The BANTAM Power Scavenger (Figure 36) is a soldier worn power and data management system that distributes and monitors power and data from various military devices. BANTAM Power Scavenger enables the user to recharge their centralized battery from various power sources without compromising operational readiness. [43], [44].



Figure 36: Bantam Power Scavenger.

5.5.3 E-Lighter® Lightweight Diesel-Fueled Power

The E-Lighter® (Figure 37), developed in partnership with Stork Fokker is a diesel powered fuel source, carried by an individual soldier. Weighing 1.8 kg and situated on the small of the back. It provides power for up to a 72 hour mission. Fully fueled, this lightweight power source, weighing only 1.8 kg, offers over 400 Wh [43], [45].



Figure 37: E-Lighter® Lightweight Diesel-Fueled Power.

5.5.4 Soldier Wearable Power System (WPS)

The Wearable Power System (Figure 38) provides power to all soldier borne equipment via an Integrated Soldier Power and Data System [46], [47].



Figure 38: Soldier Wearable Power System (WPS).

6.0 SHIP INITIATIVES

Large Military ships are like small cities in that when they are operating, they consume energy 24 hours a day, 7 days a week and are very large consumers of energy. Small changes can have a large impact on the amount of fuel a ship requires to operate. This section provides descriptive information about each of the initiatives in the Ship category along with a picture of the piece or pieces of equipment. Currently, there are twelve Ship initiatives in the OEIDB. Included are battery and battery control systems, biofuel, an energy monitoring system, ways to reduce drag such as propeller coatings and stern flaps, hybrid engine and propulsion systems, and solid state lighting.

6.1 Battery

The OEIDB contains three battery systems from the Netherlands: A Battery Control Unit, Battery Management System, and Green Orca Marine Battery Module.

6.1.1 Battery Control Unit

EST Floattech's battery control unit (Figure 39) interferes to pro-actively shut down the relevant string of batteries, if one of the individual cells exceeds its permissible values, shutting down the battery before it starts functioning beyond its critical values. During the shutdown, the other battery strings of course remain available to generate engine power. EST Floattech's BCU was the first in the maritime sector to be tested by DNV certification. Waterproof housing [48], [49].



Figure 39: Battery Control Unit.

6.1.2 Battery Management System

EST Floattech's intelligent Battery Management System (Figure 40) with active balancing supplements individual cells if required, and prevents voltage differences and thus under and overload situations [48], [49].



Figure 40: Battery Management System.

6.1.3 Green Orca Marine Battery Module

EST Floattech serves the maritime sector with clean, silent, powerful energy systems based on lithium polymer batteries. Green Orca Marine Batteries' lithium polymer batteries (Figure 41) are implemented in fully electric vessels, as well as robust hybrid combinations with a traditional diesel or LNG [48], [49].



Figure 41: Green Orca Marine Battery Module.

6.2 Biofuel

The OEIDB contains a strike group (Figure 42) fueled by biofuel from the United States. In January 2016, the U.S. Navy launched its first carrier strike group powered partly by biofuel a mix made from beef fat. The maritime branch touted the warships as the centerpiece of its “Great Green Fleet” part of a navy-wide initiative that aims to draw 50% of its power from alternative energy in four years. For now, the mix is only 10% biofuels and 90% petroleum. The U.S. Navy originally aimed for a 50/50 ratio, but the cost was too high, though that could change as competition grows in the alternative fuel industry [50], [51], [52].



Figure 42: Navy Biofuel Carrier Strike Group.

6.3 Shipboard Energy Dashboard

Energy Dashboard (Figure 43) is a shipboard tool from the United States that provides the sailor with real-time situational awareness of the energy demand associated with equipment lineups and mission. Energy Dashboard uses the Integrated Condition Assessment System (ICAS) to collect data from shipboard

equipment. The Energy Dashboard includes the Fuel Management System (FMS), which assists pre-underway planning by recommending efficient equipment lineups. Energy Dashboard calculates and instantly displays daily energy consumption rates. Energy Dashboard will raise awareness of how certain plant lineups and equipment affect fuel consumption rates. It will also build ownership in energy conservation efforts by showing how the actions of ship's force can instantly and dramatically affect fuel consumption [53].

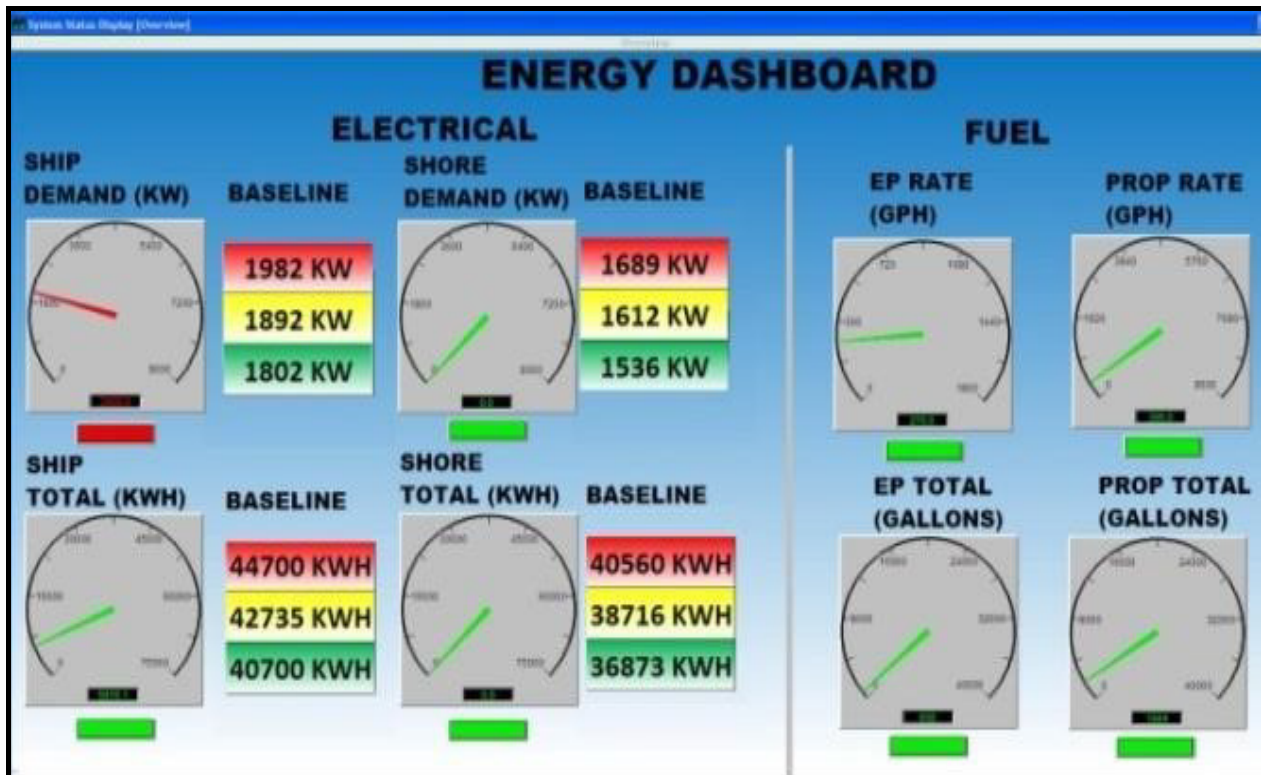


Figure 43: Shipboard Energy Dashboard.

6.4 Energy Storage Module

Single Generator Operations (SGOs) allow for one Gas Turbine Generator (GTG) to power an entire ship (Figure 44) at a more efficient level than two GTGs that are operating under 50 percent of their rated load. The Energy Storage Module (ESM) provides reliability of power, allowing for single GTG electric plant operations. It consists of a modular bi-directional AC/DC power conversion system, controls, thermal management system, and standardized system interface devices, to work with any type of energy storage device such as advanced lithium-ion battery system or conventional VRLA. The ESM Proof of Concept (POC) is a 600 kW AC-DC bi-directional advanced power converter with associated battery strings. When multiple units are installed as a system, the ESMs provide enough backup emergency power to support the ship 450VAC bus following a loss of generation casualty. This ensures that a system fault does not result in a “dark ship”, or loss of all on-board electrical power. The ESM POC synchronizes with the 450 VAC bus and monitors the bus voltage and frequency. When a loss of power is detected, the ESM draws energy from the batteries, and provides 450 VAC electricity to support the 450 VAC bus while a GTG is started and brought online. The ESM will create fuel savings by operating one GTG at optimized loading vice two inefficient, under-loaded GTGs. It also offers protection from loss of all electrical power during SGOs. Applications: DDG 51-class destroyers [53], [54].



Figure 44: Energy Storage Module.

6.5 Hull

The OEIDB contains two initiatives from the United States for the hull of the ship: Propeller Coatings and Stern Flaps.

6.5.1 Propeller Coatings

A Low Surface Energy material coating for propeller blades that reduces roughness and biofouling of ships' propeller surfaces to maximize propeller efficiency, reduce fuel consumption and minimize propeller wear (Figure 45). The unique surface properties of the coatings make it difficult for biofouling to adhere too tightly. The coating is designed so that while ships are at sea the biofouling 'sloughs off' under hydro-dynamic flow. This ensures a clean and smooth propeller during ship operations. Propellers are not traditionally coated and the bare metal surfaces require frequent cleaning. This coating material saves maintenance costs by reducing or eliminating the need to perform propeller cleanings. This coating material also improves fuel efficiency between cleanings when the ship would normally be operating with an inefficient, biofouled propeller. Propeller Coating Testing has occurred on the USS GUNSTON HALL (LSD 44), and seven propeller cleanings have been avoided over 3 years. This technology could be expanded to all surface ships [53], [55].



Figure 45: Propeller Coatings.

6.5.2 Stern Flaps

A Stern Flap (Figure 46) is an extension of the hull bottom surface which extends aft of the transom. It is a relatively small steel plate appendage that is welded to the transom. Stern Flaps modify the flow field under the hull afterbody, decreasing flow velocity and increasing pressure, resulting in reduced drag, reduced turbulence, and thus, reduced hull resistance. Stern Flaps have been proven, at sea, to increase propulsion efficiency and reduce exhaust emissions to foster significant fuel cost savings while increasing both ship speed and range. Stern Flaps decrease the strain on main engines, decrease propeller loading, cavitation, vibration and noise, and thereby increase the interval between engine overhauls and extend the service life of the propulsion machinery. Stern Flaps are currently installed (or being installed) on Cruisers (CG 47 Class), Destroyers (DDG 51 Class), and certain amphibious ships (LPD 41/17 Classes, LHD 1 Class, and LSD 41/49 Classes) [53], [55], [56].



Figure 46: Stern Flaps.

6.6 Hybrid Engine / Propulsion Systems

The OEIDB contains three hybrid system initiatives from the United States: Hybrid Electric Drive, Integrated Propulsion System, and the USS Makin Island ship.

6.6.1 Hybrid Electric Drive

The Hybrid Electric Drive (HED) (Figure 47) is a Propulsion Plant Modification that utilizes an electric motor attached to the Main Reduction Gear, allowing DDG 51 Arleigh Burke Class destroyers to operate at higher efficiency. In electric propulsion mode, the main gas turbines are secured and gas turbine generators are electrically connected to a motor attached to each main reduction gear. The propulsion load is removed from the main gas turbines and placed onto the gas turbine generators. This mode allows the gas turbine generators to operate optimally, lowering fuel consumption. By utilizing Hybrid Electric Drive, the ship can optimally load the gas turbines to take advantage of their better fuel efficiency, as well as reduce their operating time. Through the integration of mechanical and electrical systems, the ship can operate at most speeds at a lower fuel consumption, providing fuel savings and longer time on station [53], [57], [58], [59].

6.6.2 Integrated Propulsion System

LHD 8 is an innovative hybrid propulsion system (Figure 48) using both the recently developed General Electric LM2500+ gas turbine (engine rated @ 35,000 horsepower) for main ship propulsion duty and an electric propulsion system (motor rated @ 5000 horsepower) for more economical ship propulsion duty whenever practical, termed the Auxiliary Propulsion System (APS). The LHD 8 concept for electrical power generation, distribution and electric propulsion represents the intent of the all-electric warship. The purpose of the electric drive system is to provide a fuel savings as an alternative to the use of the gas turbine engines during low speed operations, where the gas turbines are less fuel efficient [53].

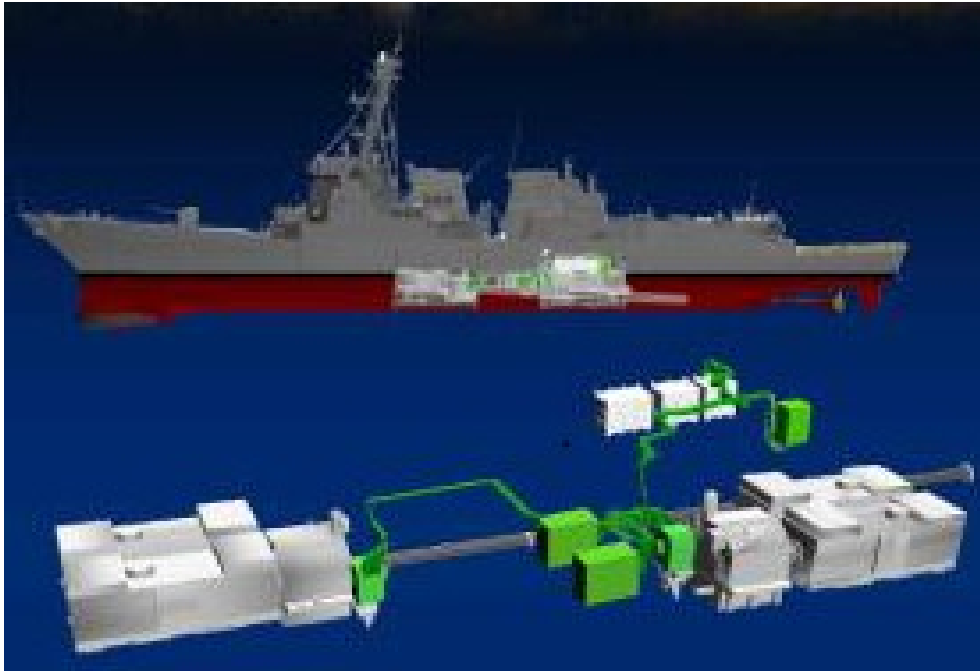


Figure 47: Hybrid Electric Drive.



Figure 48: Integrated Propulsion System.

6.6.3 USS Makin Island

USS Makin Island (Figure 49) is the first hybrid propulsion drive amphibious assault ship. The ship runs on two auxiliary propulsion motors (APMs) powered by the ship's electrical grid at low speeds (<12 knots) and on gas turbines at higher speeds. This results in lower average fuel consumption per mile traveled, reduced carbon emissions, and lower annual refueling costs. Amphibious assault ships spend approximately 75% of their underway time traveling at 12 knots or less. Therefore, Makin Island can use its electric auxiliary drive the majority of the time, saving fuel and reducing wear and tear (and related maintenance costs) on the ship's primary engines. On Makin Island, the steam plant that powers the majority of equipment on older U.S. Navy ships has been replaced by electrically powered systems, which are in turn controlled by a computer-based Machinery Control System (MCS). The MCS controls and monitors all damage control, ship propulsion, ballasting and de-ballasting, fuel fill, and selected auxiliary machinery. Eliminating the steam plant also reduces engineering department manning requirements and eliminates the workplace hazards associated with boiler systems. In addition to being the first "large deck" hybrid drive U.S. Navy ship, Makin Island is the first amphibious assault ship to be powered by gas turbines. The gas turbine/APM combination provides comparable range to steam turbine-powered ships of similar size, but uses less fuel. The combination also greatly reduces the amount of time required to bring the ship's engines online, improving the ability to quickly get underway and respond to emerging threats or humanitarian crises [53].



Figure 49: USS Makin Island.

6.7 Solid State Lighting

Light Emitting Diodes (LED) are replacements for incandescent and fluorescent lighting fixtures. SSL lamps (Figure 50) are arrays of individual LEDs producing light at the same quality and brightness as legacy lamps with an increased lifespan. Incandescent and berth lights will be replaced with fixture-form-fit-function SSL bulbs, and legacy fluorescent tubes will be replaced with SSL tubes. SSL improves energy efficiency, saves fuel at sea and saves shore power in-port. SSL also improves lamp lifespan, and drives down maintenance

and sparing costs. Removal of mercury-containing fluorescent tubes drives down handling and storage costs since SSL is not considered hazardous waste [53], [60].



Figure 50: Solid State Lighting (SSL).

7.0 RECOMMENDATIONS

7.1 Final Objectives

The third and final objective of the NATO SAS-119 RTG is to share the information that the team collected with the NATO member nations, allies and partners, and to make it accessible to them for future use and reference. The final step will be for the RTG to recommend an appropriate software platform and dashboard for containing and querying the OEIDB, and explore options and make recommendations for an appropriate home for this OEIDB, i.e., an appropriate organization to update and maintain the database, maintain the server and manage access.

7.2 Software Platform

The desirable characteristics of a software platform for supporting the OEIDB included effectiveness, ease of use, availability, accessibility, widely used and low or no cost. The database itself is in the form of a Microsoft Excel Workbook. Excel is one of the suite of tools available in the Microsoft Office Suite. The Microsoft Office Suite is nearly universally accepted throughout all of the governments of the NATO member nations, allies and partners and possesses all of the desirable characteristics. Therefore, the RTG recommends that the server that will host the OEIDB have the Microsoft Office Suite installed and the Excel spreadsheet tool activated.

7.2.1 R Shiny Data Visualization Tool

Data visualization refers to presenting data in a pictorial form. [61] The Big Data Zone website (<https://dzone.com/articles/6-ways-data-visualization-can-change-your-company>) lists seven benefits of data visualization including “communicate findings in constructive ways”, “understand connections between operations and results”, and “interact with data”. “Interactive data visualizations encourage users to explore and even manipulate the data to uncover other factors.”

There are many data visualization tools available including Tableau, MATLAB, and R Shiny. One of the most significant advantages of R Shiny is its cost. In general, R Shiny is free. There is a version of R Shiny that can cost money called Shiny Server Pro. Shiny Server Pro allows you to host the app on a server so that people can use their browsers to interact with the data. Shiny Server Pro comes with technical assistance for the Shiny Server. However, given the level of R competence among most data scientists the technical assistance should not be required.

A second advantage of R Shiny is that it is user friendly. It allows users to interact with data and produce results that are tailored to their interests or preferences. The user does not have to know anything about R or R Shiny to be able to do this. The analyst can use the R Shiny application to create a webpage that allows a user to adjust some of the parameters (in our case, the relative weights of the comparative criteria) in the assessment tool. As the user adjusts the parameters on the web page they will immediately see the results. The application is user friendly in the sense that the person that created the webpage did not have to learn an entire computer language such as HTML or javascript in order to build the webpage. Also, the person using the application does not have to have any special knowledge other than knowing how to use a webpage on the internet.

As previously stated, once you develop an R Shiny application, you have to deploy it on a server so users can access it through their internet web browsers. There are several options to do so. The application itself needs “Shiny Server” to run. An implementation of Shiny Server is free via ShinyApps (Option 1) or if you have your own server you can install the open source version of Shiny Server (Option 2). Alternatively, you can pay for Shiny Server Pro and also install it in your own server (Option 3):

- 1) **Option 1** has the advantage of being completely free and that there is no need to pay for your own server. It does rely on ShinyApps being online but this is not an impediment since it is hosted on the cloud. That makes this option fairly robust. However, you only have access to the actual database for a limited number of hours per year.
- 2) **Option 2** has the advantage of having technical support for the server (not the app) from whoever is providing the server, for example, a private company, a school, or a government agency. This option gives you unlimited access to your data, since you own the server it resides on. However, you need to have someone capable of installing Shiny Server and updating it whenever it’s necessary to do so.
- 3) **Option 3** allows you to have high level password security (via SSL) to any Shiny app you host. With this option, RStudio provides technical support for R Shiny. However, technical support for the server would still have to come from whoever is providing the server. The main disadvantage is that this option is very expensive (even with the academic pricing discount).

All of the above options allow password protected access to the content on the website. This RTG recommends using the R Shiny data visualization tool with Option 2.

7.3 Location

Determining a location for the OEIDB to reside proved to not be a simple task. There are many restrictions with respect to standing up a webserver with an outward facing web page that would allow others to access it. Most require that the data and web application be placed on a “stand-alone” server so as to eliminate the possibility that the server could be hacked and allow unauthorized access to information about anything other than what is in the OEIDB. Then there is the issue of the manpower required to maintain the server, update the software and the database, and grant access to qualified users. Many government agencies simply do not have the resources required to host the OEIDB. However, the RTG has made arrangements with the NATO Energy Security Centre of Excellence in Vilnius, Lithuania, through one of its Division heads, CDR Andrea Manfredini, to host the OEIDB. This is contingent upon that agency being able to procure a stand-alone server from the Lithuanian Government. Negotiations for obtaining the server are ongoing. Analysts from the U.S. will be responsible for installing the software on the server, standing up the webpage

and the initial management of it. Once it is established, and the amount of time to maintain it is understood, the responsibility for maintaining it will most likely be transferred to that Centre of Excellence.

7.4 Summary

In summary, the recommendations of this RTG are to:

- 1) Accept the OEIDB in the form of a Microsoft Excel Workbook.
- 2) Make the information available to appropriate representatives from the governments of the NATO member nations, allies and partners via a webpage on the internet.
- 3) Utilize the R Shiny application as the dashboard and Graphic User Interface (GUI) for the webpage.
- 4) Host the OEIDB on a server located at the NATO Energy Security Centre of Excellence in Vilnius, Lithuania.

With these recommendations, the primary effort of the NATO SAS-119 RTG is concluded. Analysts from the U.S. will continue to be engaged and work with the points of contact at the NATO Energy Security Centre of Excellence in Vilnius, Lithuania, to get the OEIDB webpage up and running.

8.0 REFERENCES

- [1] NATO STO, Technical Activity Proposal (TAP), SAS-119. 2015.
- [2] AMSAA (2019), Base Camps Component Database. June 2019.
- [3] Bolton, C. (2010), Tactical Electric Power Initiatives: Briefing from Project Manager Mobile Electric Power (PM MEP); 3 March 2010.
- [4] Richard, P. (2007), Mobile Electric Power for Today and Tomorrow; 25 April 2007. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2007/power/NDIAREgency/Wed/Session5PMMEPBriefatJointServicePowerExpo25Apr07.pdf>.
- [5] Michaelis, S. (2017), NATO Smart Energy Capable Logistician 2015; 8-19 June 2015 Hungary; 8 August 2017: https://www.nato.int/nato_static_fl2014/assets/pdf/pdf_2017_08/20170808_Smart-Energy-Ex-Capable-Logistician2015.pdf.
- [6] EST-Floatch (2019), Segments. Land Based; June 2019. www.esttechnologies.nl.
- [7] Fidelity Technologies Corporation (2014), Power Distribution Illumination System, Electrical (PDISE); October 2014. <http://www.fidelitytech.com/wp-content/uploads/2014/10/PDISE.pdf>.
- [8] Walker, A. (2011), Army Project Manager Providing More Power with Smaller Footprint; 4 September 2011. https://www.army.mil/article/64920/army_project_manager_providing_more_power_with_smaller_footprint.
- [9] Setolite (2019), Professional Lighting Solutions; 12 August 2019. <https://www.setolite.com/sites/default/files/downloads/broschueren/ALDEBARAN%20360GRAD-EN.pdf>.
- [10] Setolite (2019), Professional Lighting Solutions; 12 August 2019: http://www.natolibguides.info/ld.php?content_id=20448055.

- [11] IDE Intracom Defense Electronics (2019), Hybrid Power Systems; 2019. www.intracomdefense.com.
- [12] Renovagen (2019), Technology Hybrid Technology; June 2019. www.renovagen.com.
- [13] Banfield, Z., Golightly, J. (2014) Sustainable FOBs - Renewable Energy Technologies Assessment; 24 July 2014.
- [14] Houston, B. (2017), Remules Renewable Mobile Ultra Light Energy System; 2017. <https://docplayer.net/37237960-Renewable-mobile-ultra-light-energy-system.html>.
- [15] HDT Global (2016), SHC60 Space Heater 60,000 BTU/H Self-Powered Space Heater; March 2016. http://www.hdtglobal.com/wp-content/uploads/2015/01/HDT_SHC60_Space_Heater_12.pdf.
- [16] HDT Global (2016): Space Heater Convective 35; March 2016. <http://www.hdtglobal.com/product/space-heater-convective-35-shc35/>.
- [17] G&G Partners (2015): DEFSHELL; 2015. www.defshell.it.
- [18] Schall (2019). Rapid-Use Tent; June 2019. <http://www.mschall.de/index.php/en/military/frametents/rapidusetent-en>.
- [19] Shaaban, A. (2019), SMART Energy-Efficient Deployable Shelter (SEEDS); June 2019. <https://www.ara.com/projects/smart-energy-efficient-deployable-shelter-seeds>.
- [20] PVI (2014), PVI Designs and Delivers Customized Water Heaters for the U.S. Military; 2 January 2014. <https://www.pvi.com/service-and-support/pvi-designs-delivers-customized-water-heaters-u-s-military/>.
- [21] Anderson, G., and Maloney, S. (2013), Baseline Water Demand at Forward Operating Bases; September 2013. <https://apps.dtic.mil/dtic/tr/fulltext/u2/a613424.pdf>.
- [22] Good, B. (2011), Shower Water Reuse System to be Force Multiplier at FOBs; 19 September 2011. https://www.army.mil/article/65812/shower_water_reuse_system_to_be_force_multiplier_at_fobs.
- [23] Armistead, S. (2017), Deployable Waste-to-Energy Conversion for Expeditionary Forces; February 27, 2017. <https://www.dsiac.org/resources/news/deployable-waste-energy-conversion-expeditionary-forces>.
- [24] Force Development Directorate United States Army Combined Arms Support Command (2008). Water Planning Guide; 25 November 2008. [https://quartermaster.army.mil/pwd/Publications/Water/Water_Planning_Guide_rev_103008_dtd_Nov_08_\(5-09\).pdf](https://quartermaster.army.mil/pwd/Publications/Water/Water_Planning_Guide_rev_103008_dtd_Nov_08_(5-09).pdf).
- [25] Leonardo, DRS (2019), Expeditionary Water Packaging System (EWPS) (August 2019); <https://www.leonardodrs.com/products-and-services/expeditionary-water-packaging-system-ewps/>.
- [26] Leonardo, DRS (2019), Expeditionary Water Packaging System (EWPS) Datasheet (August 2019); https://www.leonardodrs.com/media/1907/ewps_datasheet.pdf.
- [27] TM 12359A-OD (2011), 600 Gpm Pump, Tactical Water Distribution System (TWDS); 11 June 2011. <https://www.marcorsyscom.marines.mil/Portals/105/pdmeps/docs/WATER/B2394%20-%20A.pdf>.

- [28] TM 12359A-OD (2011), Distribution Point, Tactical Water Distribution System (TWDS); 11 June 2011. <https://www.marcorsyscom.marines.mil/Portals/105/pdmeps/docs/WATER/B2393.pdf>.
- [29] TM 12359A-OD (2011), Pump, Fuel, 600 GPM; 11 June 2011. <https://www.marcorsyscom.marines.mil/Portals/105/pdmeps/docs/FUEL/B1583.pdf>.
- [30] Balling, F. (2009), Army Portable Water Treatment Units; June 3, 2009. https://www.michigan.gov/documents/deq/deq-wb-www-wss09-pres3_284554_7.pdf.
- [31] Lafontaine, D. (2013), Conformal battery unburdens Army's networked Soldiers; 16 July 2013. http://www.army.mil/article/107362/Conformal_battery_unburdens_Army_s_networked_Soldiers/.
- [32] Devcom C5ISR Center (2019), BA-5790 Battery; 12 Aug 2019. https://c5isr-ccdc.army.mil/news_and_media/BA_5790_Battery/.
- [33] SFC Energy Inc. (2019), JENNY 600S Portable Fuel Cell Power System; 13 August 2019. https://www.sfc-defense.com/sites/default/files/3_datenblatt_jenny600s_v7_en.pdf.
- [34] SFC Energy Inc. (2019), SFC Power Manager 3G; 13 August 2019. https://www.sfc-defense.com/sites/default/files/5_datasheet_powermanager3g_v5_en.pdf.
- [35] Boland, R. (2011). Marines Test Alternative Power in Afghanistan; March 2011. <http://www.afcea.org/content/?q=marines-test-alternative-power-afghanistan>.
- [36] TM 12359A-OD Extract (2011), Solar Portable Alternative Communications Energy System (SPACES); 2011. <https://www.marcorsyscom.marines.mil/Portals/105/pdmeps/docs/APS/H0011.pdf>.
- [37] Devcom C5ISR Center (2019), Energy Harvesting Assault Pack; 12 August 2019. https://c5isr-ccdc.army.mil/news_and_media/Energy_Harvesting_Assault_Pack/.
- [38] Douglas, J. US Army RDECOM (2015), Preliminary Analysis of Energy Harvesting Assault Pack; 27 August 2015. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2015/power/17829douglas.pdf>.
- [39] Xie, L., Li, X. (2017), Increased energy harvesting from backpack to serve as self-sustainable power source via a tube-like harvester; November 2017. <https://www.sciencedirect.com/science/article/pii/S0888327017302029>.
- [40] Devcom C5ISR Center (2019), 1 KW Multi-Fuel Generator; 12 Aug 2019. https://c5isr-ccdc.army.mil/news_and_media/1_Kw_Multi_fuel_Generator/.
- [41] AKT Solar (2019), 120 Watt Monocrystalline Solar Panel; 13 August 2019. <http://www.actsolar.com/index.php/en/products/off-grid-solar-panels/120-watt-monocrystalline>.
- [42] Devcom C5ISR Center (2019), 120 Watt Solar Panel; 12 August 2019. https://c5isr-ccdc.army.mil/news_and_media/120_W_Solar_Panel/.
- [43] Soldier Systems An Industry Daily (2016), Dutch Military Announces Smart Vest; 28 December 2016. <http://soldiersystems.net/2016/12/28/dutch-military-announces-smart-vest/>.
- [44] Tectonica (2019), Bantam Power Scavenger; 2019. <https://store.mssdefence.com/power-supply/1028-tectonica-tectonica-bantam-power-scavenger-power-supply.html>.

- [45] Fokker Aerostructures (2019), E-Lighter® Lightweight diesel-fueled power source for the modern soldier; June 2019. http://www.fokker.com/sites/default/files/media/Files/Brochures/Fokker_E-Lighter.pdf.
- [46] Devcom C5ISR Center (2019), Soldier Wearable Integrated Power System (SWIPES); 12 August 2019. https://c5isr-cdc.army.mil/news_and_media/Soldier_Wearable_Integrated_Power_Equipment_System/.
- [47] US Army RDECOM (2015), Development of a Soldier Wearable Power System (WPS); 26 August 2015. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2015/power/17839thampan.pdf>.
- [48] EST-Floattech (2016), Green Orca Lithium Polymer batteries; May 2016. <https://www.est-floattech.com/app/uploads/2016/05/Technical-leaflet-Green-Orca.pdf>.
- [49] EST-Floattech (2019), Commerical Vessels; 14 August 2019. <https://www.est-floattech.com/marine/commercial-vessels/>.
- [50] AP, The Guardian (2016), US Navy launches first biofuel-powered aircraft carriers; 21 January 2016. <https://www.theguardian.com/environment/2016/jan/21/us-navy-launches-first-biofuel-powered-aircraft-carriers>.
- [51] Bialystocki, N., (2016), On the estimation of ship's fuel consumption and speed curve: A statistical approach; April 2016. <https://www.sciencedirect.com/science/article/pii/S2468013315300127#fig0001>.
- [52] U.S. Department of Energy, Alternative Fuels Data Center (2019), Biodiesel Blends; 14 August 2019. https://afdc.energy.gov/fuels/biodiesel_blends.html.
- [53] U.S. Navy Energy, Environment and Climate Change (2019), Tactical Ship Energy Fact Sheets; 14 August 2019. <https://navysustainability.dodlive.mil/library/fact-sheets/energy-fact-sheets/tactical-fact-sheets/>.
- [54] U.S. Navy Energy, Environment and Climate Change (2019), Energy Storage Module (Proof of Concept); August 2019. <https://navysustainability.dodlive.mil/files/2012/06/Energy-Storage-Module.pdf>.
- [55] Live Better Magazine (2012), US Navy RADM Eccles: Surface Ship Energy Efficiency Initiatives; 19 January 2012. <http://livebettermagazine.com/article/u-s-navy-radm-eccles-surface-ship-energy-efficiency-initiatives/>.
- [56] NAVASEA (2009), Scaling Effects on Stern Flap Performance Progress Report; September 2009. <https://apps.dtic.mil/dtic/tr/fulltext/u2/a507858.pdf>.
- [57] Defense Industry Daily (2012), US Destroyers Get a HED: More Power to Them!; 9 May 2012; <https://www.defenseindustrydaily.com/us-destroyers-get-a-hed-more-power-to-them-07142/>.
- [58] GE (2019), GE's Marine Solutions Showcases Power, Propulsion and Digital Analytics, Ideal for Future Surface Combatants; 15 January 2019. <https://www.gepowerconversion.com/press-releases/ge%E2%80%99s-marine-solutions-showcases-power-propulsion-and-digital-analytics-ideal-future>.

- [59] LaGrone, S. (2016), Navy Set to Install Hybrid Electric Drives in Destroyer Fleet Starting Next Year; Winter 2016. <https://www.public.navy.mil/surfor/swmag/Pages/Navy-Set-to-Install-Hybrid-Electric-Drives-in-Destroyer-Fleet-Starting-Next-Year.aspx>.
- [60] Viribright (2019), Comparing LED vs CFL vs Incandescent Light Bulbs; August 2019. <https://www.viribright.com/lumen-output-comparing-led-vs-cfl-vs-incandescent-wattage/>.
- [61] Cordray, R. (2017), 7 Benefits of Data Visualization; 5 July 2017; <https://dzone.com/articles/6-ways-data-visualization-can-change-your-company>.





NORTH ATLANTIC TREATY ORGANIZATION
SCIENCE & TECHNOLOGY ORGANIZATION



TECHNICAL ACTIVITY REPORT

Panel/Group	SAS	Activity Title Energy and Defence: Reducing Dependencies & Vulnerabilities – Enhancing Efficiency	
Reference Number	SAS-119		
Activity Type	Task Group		
Panel Approval Date 08 May 2015	Board Approval Date 01 Nov 2015	Activity Start Date 24 Feb 2016	Activity End Date ~~24 Feb 2019~~ 24 Sep 2019
Related Activity	SAS-118		
Projected Meeting Location(s)	1st Meeting: 24-26 February, CSO, Paris		
Lead Nation(s)	United States		
Team Leader(s)	Mr. Morris HAYES (USA)		
Panel/Group Mentor			
NATO Nations/Orgs Invited to Participate	COE-ENSEC		
NATO Nations/Orgs who Endorsed the Activity	CZE POL ROU GBR LTU NLD USA ACT		
Non-NATO Nations/Orgs Invited to Participate	STOEOP PfP MD GP		
Security Classification Level or Marking of the Activity	NATO Unclassified (NU)		
Keywords	Alternative Fuels, Applied Energy Technology, Emerging Security Challenges, Energy Efficiency, Energy Security, Tactical Power Production		
NATO and National Resources Required	TBP		

TECHNICAL ACTIVITY REPORT

BACKGROUND

Developments during recent decades have put the issue of energy on the NATO security agenda. Frequent terrorist attacks on NATO fuel convoys in Afghanistan and Pakistan have led to an increased awareness within the Alliance of the crucial role of energy supply in missions which involve long distances and sustained presence. NATO's present energy security agenda emphasizes three major areas: 1) raising strategic awareness of energy developments with security implications, 2) contributing to the protection of critical energy infrastructure, and 3) enhancing energy efficiency in the military. This activity supports NATO's energy security agenda by focusing primarily on the third major area – specifically enhancing energy efficiency through applied technical solutions concentrating on the crucial role of operational energy (OE).

MILITARY RELEVANCE

At the 2008 NATO Bucharest Summit, the Allies noted a report on "NATO's Role in Energy Security," which identifies guiding principles and outlines options and recommendations for further activities. Since then, Allies have struggled to define NATO's role in key areas such as projecting stability and advancing international and regional cooperation without changing the framework agreed at the Bucharest Summit. Within its present energy security agenda, NATO's focus lies on three major areas; 1) raising strategic awareness of energy developments with security implications, 2) contributing to the protection of critical energy infrastructure, and 3) enhancing energy efficiency in the military.

SCIENTIFIC OBJECTIVE(S)

The overall objective of this activity is to contribute to energy security within NATO, NATO nations and partner nations, by examining several key areas of interest, sharing information and approaches to enhancing energy efficiency, and promoting best practices amongst NATO members with respect to enhancing energy efficiency in those areas. The NATO Centre of Excellence for Energy Security and Allied Command Transformation are integrated into this research effort.

EXPECTED ACHIEVEMENTS

The key aspect of this activity is to make the most out of limited resources by building on existing work and leveraging successfully fielded energy-saving science and technologies rather than duplicating what has already been done, within NATO as well as within the participating nations' Ministries of Defense.

SCIENTIFIC TOPICS TO BE COVERED

This activity will rely mainly on qualitative research, to include subject matter expert interviews and/or surveys within the member states' MoD's to determine already sponsored/initiated/conducted projects throughout the Alliance.

To some degree there is also a need for consequence management in order to see how interoperability is maintained if new techniques are not streamlined (e.g. various fuel mix between countries).

SYNERGIES AND COMPLEMENTARIES

Initiatives that focus on energy efficiency are already being conducted within NATO; two examples are Smart Energy Team (SENT) and Innovative Energy Solution for Military Applications (IESMA). This activity will also provide input to the Emerging Security Challenges division at NATO HQ to support their work on energy security.

EXPLOITATION AND IMPACT

Making wise use of limited resources and avoiding duplication is crucial. This will be accomplished through partnership exchange, a key process that will be facilitated by this activity. The collection and sharing of experiences, lessons learned and successful application of S&T advancements will demonstrate that NATO is committed to enhancing energy efficiency of military operations. The value of such an approach is multifaceted. Enhanced energy efficiency not only reduces fuel costs but also minimizes operational risk (on average, one US soldier died for every 24 fuel convoys in Afghanistan; and for each gallon of fuel delivered, up to four gallons were consumed for transport). The activity will also develop a platform to improve the exchange of best practices and will support training and education to promote an energy efficient culture.

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14. Abstract	By being a large consumer of energy, especially fossil fuels, the armed forces of most Allied nations are highly dependent upon imports from countries that are located in unstable regions beyond Allied influence. Developments during the latest decades have put the issue of energy on the NATO security agenda. Within that agenda, NATO's focus is on three major areas: 1) Raising strategic awareness of energy developments with security implications; 2) Contributing to the protection of critical energy infrastructure; and 3) Enhancing energy efficiency in the military. The NATO Systems Analysis and Studies 119 (SAS-119) Research Task Group (RTG) focused on the third major area, reducing dependencies on energy resources outside of the Alliance by enhancing energy efficiency through applied technical solutions, focusing on operational energy. The objectives of the RTG were to: 1) Gather information on successfully implemented OE initiatives; 2) Develop a methodology for assessing the relative goodness of those initiatives enabling those interested in implementing OE initiatives in their own military to determine which were most pertinent or desirable based on their own requirements; and 3) Share that information with the NATO member nations, allies and partners, and make it accessible to them for future use and reference.		





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