A moment of maritime opportunity? The operational energy challenge

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Synopsis

The 2022 National Defense Strategy places the U.S. Navy's primary focus on its most consequential strategic competitors armed with long-range weapons and significant anti-access/area denial (A2/AD) systems, as well as substantial cyber capabilities. It is recognized that the integration of weapon platforms between the U.S. Navy and its Allies and Partners provide an asymmetric advantage against adversaries. As energy intensive capabilities designed to sustain and enhance warfighting lethality emerge and are fielded, the U.S. Navy's operational energy demand continues to increase. As operational energy demand increases, the Department of Navy targets strategies to reduce the threat of climate change. The Secretary of the Navy has addressed operational emissions by focusing on initiatives that decrease emissions while increasing capability as part of the government's net-zero emissions goal by 2050. The U.S. Navy recognizes that new approaches and innovative technologies are required to modernize platforms for energy reduction, increased endurance, enhanced operational flexibility, and to support forward presence. Updated energy parameters are necessary to drive technology innovation and policy.

Keywords: Operational Energy, Climate, Technology, Partnerships, Performance Parameters

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1. Introduction: Threats, challenges, and climate change

> *“From the East China Sea, to the Arctic, to the Black Sea, authoritarian states are violating the territorial and economic sovereignty of other nations.”*
>
> Hon. Carlos Del Toro
> 78th Secretary of the United States Navy
> Remarks at Daniel Inouye Asia-Pacific Center for Security Studies, 14 June 2022

The pace of change in the maritime domain has accelerated, with several nations now contesting the balance of power in key regions around the world. (Berger, Gilday, Schultz, 2020). The U.S. Navy is now facing new challenges from adversaries who are gaining technological advances and expanding their ability to conduct combined operations (Gilday, 2022). In order to pace the projected threat, platforms require more powerful sensors and new capabilities, including hypersonic and directed energy weapons (Shyu, 2022). These platforms will operate as integrated force packages that range from an individual ship with multiple off-board systems to multi-ships and systems with a common integrated combat system to maximize the benefits of distributed operations. Such improvements, however, need to be coupled with new approaches that effectively extend the operational reach of systems while increasing combat capability through the effective use of energy.

1.1 Threats to Euro-Atlantic security

The security challenges facing the United States, its Allies, and partners are only becoming more complex as additional long-term commitments are being made to bolster European security. Since February 2022, U.S. Navy regional presence has surged to reinforce deterrence and defense in the face the European security crisis (LaGrone, 2022). “We will work on ways to best align our collective strength to deter conflict, and if called upon, respond quickly and effectively,” according to Vice Admiral Gene Black, Commander U.S. Sixth Fleet at the 2022 Cooperative Strategy Forum (U.S. Sixth Fleet Public Affairs, 2022). “We have an obligation to maintain readiness and demonstrate a credible and capable maritime force, which will maintain freedom of the seas, ensure free economic exchange, and maintain maritime security.” At the June 2022 Madrid Summit, NATO leaders shifted the focus of the Alliance's deterrence and defense posture, agreeing to strengthen forward defenses, increase investment, bolster the number of ready forces, and adopt a new Strategic Concept. The summit also saw the invitation of two Nordic states, a significant step forward for Euro-Atlantic security.

1.2 Challenges in the Indo-Pacific

At the same time, growing multi-domain threats are clearly reflected throughout the 2022 National Defense Strategy (NDS). “None of us should accept changes to the status quo brought about by coercion or force,” said Admiral John Aquilino U.S. Indo-Pacific Command (INDOPACOM) during testimony the June 2022 Shangri-La Dialogue security conference held in Singapore (Dominguez, 2022). “Instead, we should act together to strengthen the rules-based international order that has served us so well.” The Asia-Pacific region is a key global economic driver, with the busiest international sea lanes and 9 of the 10 largest ports. The USINDOPACOM Area of Responsibility (AOR) “encompasses about half the earth's surface, stretching from the waters off the west coast of the U.S. to the western border of India, and from Antarctica to the North Pole” and includes the majority of the world’s population across 36 countries and 16 time zones (USINDOPACOM Public Affairs, 2022). Given these conditions, the geostrategic complexity the U.S. faces in the region is unique.

1.3 Climate change

Climate change is expected to intensify the rate of trans-boundary threats the U.S. Department of the Navy will need to meet. This further consideration will require the U.S. Navy to adapt to meet new operational requirements, respond to increasingly common humanitarian response missions, promote regional stability, and address growing risks and security tensions within a rapidly changing Arctic region. The Department of the Navy’s Climate Action 2030 strategy builds on a decades-long foundation of climate action across the Navy and Marine Corps and sets the DON on a course to meet national and global targets to reduce the threat of climate change. The Secretary of the Navy has addressed operational emissions by focusing on initiatives that decrease emissions while increasing capability as part of the government’s net-zero emissions goal by 2050. Within this context, the U.S. Navy will continue its efforts to advance “hybridization, electrification, alternative lower-carbon fuels, and advanced propulsion solutions for both existing and future tactical platforms in all domains.” Both the U.S. Navy and NATO recognize the challenges and risks that climate change presents to global security (NATO, 2022).

The remaining sections of this paper are organized as follows: First, the importance of Operational Energy is outlined together with the role of assured delivery of energy to enable missions, increase warfighting capability, and reduce risk. We then present key technology developments and the partnerships that are advancing the generation, storage, control and distribution of energy in the context of delivering integrated all-domain naval power. We conclude with a summary of progress applying an Energy Key Performance Parameter (KPP) for future platform and system design efforts.

2. Background: The operational energy challenge

> *"America has always been a maritime nation. The seas are the lifeblood of our economy, our national security, and our way of life."*
>
> Admiral Michael M. Gilday
> 32nd U.S. Chief of Naval Operations
> Navigation Plan to the Fleet, 26 July 2022

When examining U.S. Navy energy requirements there are two distinct categories that apply: installation energy and operational energy. Installation energy is broadly defined as the energy required to heat, cool, and power buildings at the Navy's fixed installations, as well as the energy consumed by its non-tactical vehicle fleet. For example, facility energy accounts for approximately 25% of the Navy's total energy consumption (Caley, 2021). Installation energy is a factor of the Navy's total energy portfolio; however, it is outside the scope of this paper. Operational energy, the focus of this paper, is defined in U.S. law by Title 10 U.S. Code statute as "energy required for training, moving, and sustaining military forces and weapons platforms for military operations" (10 U.S. Code § 2924(5)). The term includes energy used by tactical power systems and generators and weapons platforms, as well as encompasses energy in all forms to support associated enabling technologies.

Operational energy encompasses the energy required to prepare for and move the Fleet from homeport bases to forward locations to deliver effects that deter and compete with peer and near-peer competitors. Since transitioning from counter-insurgency operations to global deterrence and strategic competition, the U.S. Navy faces significant challenges enhancing lethality and effectiveness through energy resilience, operational reach, and time on station (Figure 1). Fuel demand across the U.S. Fleet is expected to increase 15% by 2030, while electrical demand for deployed expeditionary forces is 26% and advanced weapons and sensors will more than double shipboard electrical demand by 2030 (Caley, 2020).

Figure 1: The Operational Energy Challenge

The U.S. Navy's operational energy demand continues to increase as energy intensive capabilities designed to sustain and enhance warfighting lethality emerge and are fielded. High energy radars and sensors and directed energy weapons are shifting the paradigm from ships whose depth of fire are limited by the number of missiles or rounds in magazines to the amount of electrical energy that the power plant can produce and sustain. Effectively, energy storage in the form of fuel tanks, batteries, and capacitors are becoming the magazines of the future force. Advances in technologies that maximize the efficiency of energy conversion, distribution, and storage will increase lethality, extend operational reach, time on station, endurance, and the ability to adapt to evolving energy needs. Building a resilient Joint Force and defense ecosystem will require a holistic approach to optimizing operational effectiveness in contested environments.

The U.S. Fleet has been able to achieve gains through new approaches and innovative technologies in recent years, however building upon the efficiency gains will become more challenging as the initial list of "low hanging fruit" is consumed. Examples of energy reduction improvements to date have typically been incorporated as form, fit, and function replacements at the equipment-level. As these initiatives are realized, the U.S. Navy will need to turn to more complex system-level improvements with larger ship integration impacts. The Navy must meet the challenge of building upon the efficiency gains while simultaneously dealing with shorter ship development and modernization cycles and longer development timeframes for new and innovative technology. This dilemma requires the U.S. Navy to create and maintain a well-defined plan to mobilize support for fundamental improvements in operational energy and drive alignment across the naval enterprise. The plan must support both strategic and operational perspectives and be sure to leverage technology and system level investment across platforms. The plan must acknowledge that energy is a fundamental enabler of military capability. Likewise, the ability for the U.S. Navy to project and sustain power necessary for defense depends on operational energy.

2.1 Fleet design priorities

The capabilities and force architecture necessary to execute the U.S. Navy's operating concepts are reliant upon energy supply and demand. For example, when fighting forward, competitors have the benefit of a short supply chain that includes an advantage in operational energy supply lines. The U.S. Navy is working to incorporate energy command and control, demand management, and resilient supplies as an approach to overcome the competition's advantage and maximize the benefits of distributed operations. Further, the U.S. Navy understands that considerable work is needed within the operational energy domain as it shifts from asymmetric threats and an anti-terror focus on a near-peer operational environment. This shift in focus is necessary to ensure that the U.S. Navy is ready to win across the full range of military operations in competition, crisis, and contingency by persistently operating forward with agility and flexibility in an all-domain battlespace demands.

2.1.1 U.S. Navy current and future fleet

The U.S. Navy Total Battle Force is expected to expand to as many as 321 to 372 ships by 2045, or 398 to 512 total platforms by 2045 when including unmanned surface and subsurface platforms (OPNAV N9, 2022). With the increasing number of ships, there is need to consider energy supply and demand to maintain flexible and efficient warfighting capabilities. The scope of the ship increase includes the recent launch of the first DDG 51 Arleigh Burke-class guided missile destroyer to be built in the Flight III configuration, which is designated as the future USS Jack H. Lucas (DDG 125). The increase also includes a greater number of San Antonio-class amphibious transport dock ships, including the future USS Harrisburg (LPD 30), the first LPD 17 Class Flight II ship. It must be recognized that the engineering plant designs of these ships, combined with their projected high operating tempo, contribute to a trend of growing fuel consumption demand. Historically, U.S. Navy surface ships have been primarily designed to accommodate maximum combat capability and range, with fuel consumption rate considerations being a secondary function of operating ability. As the U.S. Navy looks to the future, it sees a continued need for naval forces on station to meet the mission requirements of the Joint Force and Combatant Commanders.

2.1.2 Operational energy priorities

In view of the growing importance of operational energy considerations, the Secretary of the Navy directed the Chief of Naval Operations (CNO) to establish measurable objectives as outlined in memorandum of 27 June 2019 entitled "Department of the Navy Operational Energy Goals". The purpose of the directive was to ensure naval operational energy challenges are addressed. According to this new direction the Navy and Marine Corps must enhance the lethality and effectiveness of forces through energy resilience, operational reach, and time on station of forward presence naval forces (SECNAV, 2019). Specifically, this guidance focuses on:

- Extending operational reach of current and future weapons systems through more effective use of energy;
- Reducing energy consumption and external energy logistics requirements to forward deployed strike groups and expeditionary units;
- Increasing energy resilience of forward bases, supply depots, and cooperative security locations to get more energy to the warfighter;
- Increasing the effective use, conversion, storage, distribution, and control of energy to enable the integration of future weapons and sensors onto platforms; and
- Fostering and guiding an energy culture in our Marines and Sailors through policy, training and education

The U.S. Navy's warfighting strategy, focused on distributed operations, prioritizes sustained operations forward in all domains and in denied environments. This strategy stresses the force architecture and significantly challenges the operational energy network. Further, the operational energy goals of the U.S. Navy focus on closing technological gaps in the recently developed warfighting Concept of Operations (including DMO). The warfighting concept calls for weapon systems and platforms with increased stand-off, greater range, increased time-on-station, and other energy-relevant operational energy capabilities. The concept includes unmanned platforms requiring longer ranges, greater persistence, and reduced detection profiles in order to reduce risk to manned platforms and provide persistent Intelligence, Surveillance, and Reconnaissance (ISR).

3. Establishing a foundation for transformation: Key technology developments and partnerships

The U.S. Navy recognizes that new approaches and innovative technologies are required to modernize platforms for energy reduction, increased endurance, enhanced operational flexibility, and to support forward presence. At the same time there is a need to reduce the vulnerability inherent in distributing fuel in contested operating environments. As a result, operational energy has become a strategic imperative. With the U.S. Navy's global presence and operations, assured access to reliable and sustainable supplies of energy is central to successful operations. To maintain effective countermeasures to evolving threats, the U.S. Navy continues to enhance the lethality and effectiveness of forces through increased energy resilience, operational reach, and greater time-on-station. Achieving the necessary capability enhancements will require sustained investment and a focused plan to modernize platforms for energy reduction.

3.1 Key technology developments

The U.S. Navy's operational energy goals are even more meaningful given the fact that the amount of electrical power used aboard surface ships has grown exponentially over the past century. With the continued increase and proliferation of technologically sophisticated ballistic and anti-ship cruise missiles, there is an associated need for the fielding of enhanced sensor and weapon system capabilities. Additionally, the evolution of asymmetric threats requires new technology solutions for lethal and non-lethal shipboard defense systems. As such, several disruptive technologies will be introduced over the next several years to enhance mission capability and lethality, such as directed energy weapons, deployable unmanned platforms, and high energy sensors. These technologies will not only drive an increase in installed power requirements that more than double by 2030 but also shift the depth of fire from the magazine to the fuel tank (Caley, 2021).

Implementing an integrated approach to satisfy increasing shipboard power demands and high operational tempo, while substantially improving energy efficiency will be a challenge for the naval engineering community. This approach must consider the modernization of the legacy in-service fleet as well as the design necessary for the future classes. To meet this need in support of the warfighter, there must be a fundamental paradigm shift in future ship hull, mechanical, and electrical (HM&E) design from traditional to integrated architectures. Such a shift will close the affordability gap and will enable access to all installed power thereby increasing available power at a lower cost while maintaining mission capability.

Advances in material science, computing, and engineering offer opportunities to mitigate risks and capitalize on energy demand reduction for joint operations, which in turn reduces risk to the force and risk to mission in contested environments. It is clear, the ability to operate for extended periods and over longer distances will directly increase capability and reduce the adversary's opportunity to disrupt operations. Emerging operational energy technologies will drive the design of Navy's future capabilities by enhancing lethality and effectiveness of forces through energy resilience, operational reach, and time-on-station of forward presence naval forces. (SECNAV, 2019). Research to mature emerging technologies and modernize existing technologies in power generation, conversion, storage, management, and distribution in an operationally relevant environment is crucial to maximize operational effectiveness and efficiency.

The overarching ontology of operational energy begins with an energy source that is used for power generation and energy conversion or energy storage. Controls and power management is both an input and output of power generation, conversion, and storage. Power is then distributed to platform systems and operational loads (OSD, 2022). Current U.S Navy ships have a similar power systems architecture where energy, in the form of fuel, flows into a ship's prime movers to convert energy and generate power, which then is either stored for later use or is conditioned and distributed to provide power for propulsion and ships service loads. Specifically, F-76 Military Diesel fuel flows into diesel engines and gas turbine gensets and is converted to electrical power. That electrical power is then conditioned using power management and control technologies to be distributed through transformers and semi-conductors to support weapon systems, power auxiliary loads, and provide propulsion and platform power. The overarching power system architecture is shown in Figure 2.

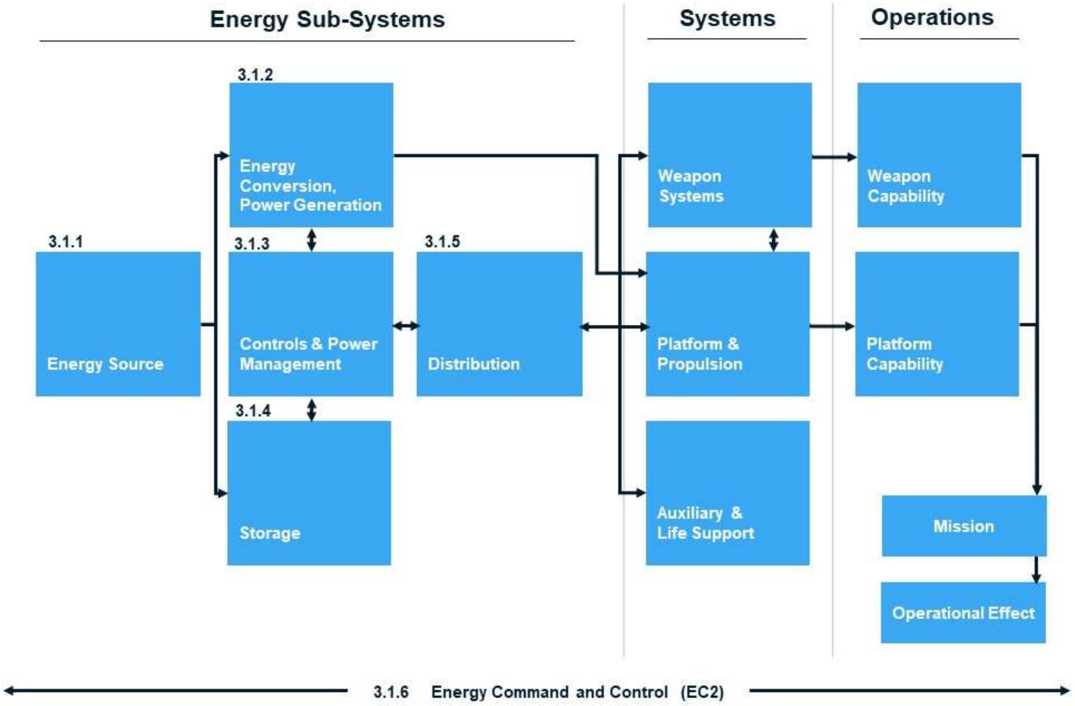

Figure 2: Operational Energy Ontology

3.1.1 Energy source

Diesel fuel is the initial input into a ship's power system architecture. The current F-76 Military Diesel fuel used by the U.S. Navy is a non-sustainable fuel source with considerable toxic emissions. Renewable fuel sources to be used in lieu of, or in conjunction with current fuel to create sustainable power ensures resiliency and reliability. The use of alternative renewable fuels, specifically hydrogen and biofuels, to efficiently generate power and reduce carbon emissions are at the forefront of research in energy optimization. Hydrogen is a fuel source that is abundant and energy efficient, while supporting zero-carbon emission initiatives. Many technologies are emerging that enable efficient hydrogen production. Navy and partners are currently studying existing hydrogen electrolysis technologies to determine effective methods for surface vessels and unmanned-underwater vessels (Thorson et. al, 2021). Hydrogen injecting technologies that increase fuel burn to optimize fuel efficiency and reduced carbon emissions is another area being heavily researched in industry and academia (Bayramoglu and Yilmaz, 2021). A major roadblock with hydrogen in shipboard applications is limitation to storage regarding location on a ship, safety, and survivability. Efforts in hydrogen storage focus on analyzing and comparing existing methods such as compressed storage, liquid storage, alternative carries, and solid-state storage to determine practical applications (Inal et al., 2021).

Research on biofuels to increase energy supportability while limiting emissions is being conducted in both industry and academia. Navy has pursued the use of biofuels, but implementation of this technology is limited pending the ability for biofuels to meet NATO and military standards. The Fiscal Year 2022 Operational Energy Budget Certification Report identifies funding for the U.S. Naval Research Laboratory to explore the augmentation of liquid fuels for greater energy density and exploitation of biological mechanisms for long duration energy sources (DOD, 2021). Usage of alternative fuels in U.S. Navy assets poses integrations challenges with existing prime move technology. Conscious decisions have been made by the U.S. Navy to follow commercial adoption of both hydrogen and biofuels until these technologies meet the required standards.

3.1.2 Energy conversion and power generation

Energy as fuels will continue to be used by the U.S. Navy to enable power generation through a ship's prime movers. Prime movers are crucial in a ship's power plant, as they provide the ship's main propulsion power and electrical power for service loads. Most modern surface combatant power and propulsion architectures fall under either mechanical drive, integrated power systems, hybrid drive, or hybrid drive with propulsion derived ship service power (Doerry and Amy, 2020). Major breakthroughs to prime mover technologies in ships have been limited in recent years. Current efforts to enhance prime mover technologies, such as engine and generators, focus on incremental optimization, rather than large advances. The Department of Defense is funding a "High Efficiency Generator" initiative in 2022 that will evaluate and demonstrate alternative aircraft power generation and conversion technologies to provide more efficient power generation to meet legacy platform deficiencies (DOD, 202 1). Future initiatives will reduce time on station and maintenance requirements through the development and use of materials that resist corrosion and oxidation and maintain desired characteristics at high temperatures. (Sifler and Hoffman, 2021). Power conversion efforts to effectively process and control energy to support varying loads have been focused on advancing power electronics by optimizing inverters, converters, and semi-conductors. Electrical power from the prime movers is then conditioned with power management and control methods before distribution to various shipboard systems.

3.1.3 Controls & power management

Efforts in advanced power controls and sensors to monitor and analyze varying electrical loads are becoming imperative to understand current and future load requirements (Vu et al., 2018). Future weapons with non-linear loads will require systems that can maintain power quality and ensure stable load integration. Control capabilities will also be enhanced as data analytic software matures to allow for automated monitoring. Non-intrusive load monitoring efforts have enabled advanced capabilities in power monitoring such as the ability to manipulate load actuation metrics and acquire power trace data as a whole. Data gained from these advances have enabled efforts to create a reliable power simulator to model real and theoretical shipboard power systems in various operating condition. Accurate real time and theoretical power simulation would support development and design of future combat capabilities (Kidwell, 2020). Ensuring power reliability and resiliency will require advanced controls to provide a distribution bus suitable for servicing highly dynamic mission loads and propulsion demands to be integrated with safe and effective energy storage technologies.

3.1.4 Energy storage

Energy storage will enhance survivability, reliability, and flexibility while providing new capabilities such as the ability to quietly maneuver solely on energy storage. Energy storage technologies should support cross-platform integration and adaptive fielding of weapons systems through standardization metrics (Department of Navy, 2019). The standardization of batteries and battery interfaces is of high interest to the U.S. Navy. Current emerging battery technologies are limited by safety requirements and maximum power densities. Lithium-ion (Li-ion) batteries have surpassed capabilities of valve regulated lead-acid batteries and meet the desired power density requirements (Keshan et al., 2018). Li-ion batteries are now widely used in various applications, but present challenges with storage, fire safety/management, and supply chain. The FY22 OEBCR highlights Navy funding to continue research in Li-ion propagation resistant battery architecture including integration and demo in a medium unmanned underwater vessel. The FY22 OEBCR also shows Navy funding efforts in battery safety certification to increase rapid and safe deployment as well as efforts to increase battery commonality. Advanced batteries are an example of research in electrical/chemical energy storage. Research in thermal and mechanical storage is ongoing, though shipboard implementation for these types of energy storage are in much earlier design stages (Catapano et al., 2022).

3.1.5 Distribution

For the purpose of this paper, distribution in power systems will be focused on the technology used to transmit power, configure a power system, and protect systems from electrical faults (DON NPES TDR, 2013). Gaining efficiency in electrical power distribution is becoming more imperative as the U.S. Navy's power and energy demands increase and the use of direct current (DC) at higher voltages for efficiency in transmission becomes more prevalent (DON NPES TDR, 2019). Current Navy efforts focus on advances in material science to obtain ideal material properties are allowing higher voltages and currents to be safely utilized to meet higher electrical load requirements, while reducing size, weight, and thermal loss (DeGiorgi et al., 2019). Power electronics are being researched to control voltage, frequency, and power factor and improve reliability and stability of transmission. Research to design high temperature superconducting power cables that tolerate fault conditions is ongoing as Navy integrates DC power into systems (Cheetham et al., 2019). An efficient distribution system enables increased survivability, flexibility, and overall capability through increased redundancy, more capable power continuity, and increased recoverability.

3.1.6 Energy command and control

Emerging technologies in operational energy are an integral part of the solution to increase energy resilience and operational effectiveness of combat platforms. As energy demands increase, the ability to understand the energy inputs and outputs of both the internal shipboard systems and the entire operating theater becomes imperative to informing decisions on energy optimization. A holistic view of operational energy requires discussion about energy command and control (EC2). Effective EC2 requires accurate understanding of long-term force sustainment metrics and global resource limitations to prioritize operational decisions. Challenges associated with EC2 include anticipating requirements in stressed operating environments and integrating sustainment capabilities. Advances in command and control (C2) technologies and at-sea replenishment strategies will enable the current and future operating capabilities required to rapidly deploy and aggregate forces (Joint Staff J7, 2020).

Updated EC2 strategies are necessary to support new warfighting concepts such as Littoral Operations in a Contested Environment (LOCE), Distributed Maritime Operations (DMO), and Expeditionary Advanced Based Operations (EABO). Current EC2 efforts are focused on data collection, data transport, data aggregation, exposure and visualization, supporting data, and planning and forecasting. Understanding operational data informs decisions on optimizing at-sea replenishment efforts. Sea-based Petroleum Distribution System (SPDS) and Joint Offshore Fuel Farm (JOFF) are current fuel storage and distribution efforts aimed to improve legacy systems by making underway replenishment more efficient (DOD, 2020).

Advancing technologies to optimize all aspects of operational energy will ensure a reliable and sustainable joint force. Efficiency gained from emerging technologies will reduce energy demand and enable future capabilities to increase lethality. Power and energy demands will continue to increase, and it is imperative that state of the art technologies are being developed to modernize the current Fleet and guide design for future Fleet. Investment into research to enhance energy conversion, power generation, energy storage, distribution, and energy command & control is crucial to enhancing operational energy capabilities.

3.2 Advancing partnerships

The integration of weapon platforms between the US Navy and its Allies and Partners provide an asymmetric advantage against adversaries. However, this advantage holds true only if all parties have an accurate and shared understanding of each other's military and commercial capabilities. Through wargames and exercises, the US Navy evaluates risks to future posture and operational plans. For example, Joint Force Energy Wargames were recently conducted that brought together different Services, Combatant Commands, Allies, and US Partners to explore and assess strengths, weaknesses and consequences of alternative approaches to operational energy (Braesch, 2019). Recent exercises have also recently been applied, which analyzed the potential contributions of Allies and Partners in addressing gaps in sustainment and supply of energy requirements. The wargames provided the Joint Staff, Services and Combatant Commands the opportunity to explore future concepts and capabilities and contribute to future planning efforts pertinent to overarching force design and developmental efforts as well as strategic investment strategies for logistics and operational energy solutions.

3.2.1 Domestic

The U.S. Navy has long standing relationships with the domestic maritime industrial base, Department of Energy National Laboratories, and several research universities and academic research labs. These relationships and partnerships have driven operational energy innovation over the last century and in the past decade have delivered advanced energy technologies such as the hybrid electric drive in the DDG-51 Arleigh Burke destroyers and the integrated propulsion system (IPS) in the DDG-1000 Zumwalt destroyers. Though these long-standing relationships will continue to serve as the foundation of the Navy's energy innovation partners, current efforts are underway to expand Navy's partners for energy innovation, development, and transition of operational energy technologies.

A constant challenge and even impediment to the development and transition of energy technologies is the opportunity and ability to test those technologies in an operationally relevant environment. In 2019, Congress took deliberate action to reduce some of this impediment by investing in Navy land-based testing and engineering sites. While these test-sites do provide some operational context for testing energy technologies within a ship systems environment, they do not replicate or replace the unique maritime environmental factors, motion in three-dimensional space, shock or vibrations, or ungrounded electrical systems in salt water. Some knowledge can only be gained, and some technological risks can only be reduced through shipboard testing. However, testing energy technologies in Navy combatants is often not feasible from operational and fiscal perspectives. Not only is testing administratively burdensome and problematic to schedule, but the tests often yield limited data sets to inform engineering and programmatic decisions. Dedicated testing assets are prohibitively expensive to acquire, operate, and maintain.

The U.S. Navy does not operate the only domestic fleet of surface vessels in the U.S. Other government agencies, including some long-standing Navy partners, own and operate a variety of surface platforms around the country. Not only do these agencies and partners have their own motivations and interests in developing energy technologies but they also have their own reasons to establish relationships and team with the Navy for the purpose of testing energy technologies. In recognizing this opportunity to further operational energy pursuits, the Navy is taking a concerted effort to establish, develop, and strengthen relationships with federal and state maritime partners for the purposes of developing and transitioning operational energy technologies.

Recognizing that similar efforts in the past constrained and limited their utility by establishing ridged agreements and resource requirements upfront, this new effort, resourced by the CNO's staff and advocated for by the Secretary's Operational Energy Office, is above all else, aimed at bringing together the engineers, technologists, and technical points of contact with similar and overlapping areas interest and research in the operational energy space. The range of engagement can span from simple information and knowledge sharing to very specific projects that are integrated with objectives, requirements, and resources. By maintaining such a broad approach, the Navy is able to both push and pull energy innovation and be more efficient with investment resources and technologist bandwidth.

3.2.2 International

Strategic competitors continue to vie for increased influence and in doing so will actively seek to exploit seams in operational energy architectures as a mean to outcompete or defeat the United States and its Allies and Partners. A chief goal for avoiding gaps in the operational energy architecture and to overcome current and future challenges is by refining overall operational energy demands. To achieve this end the US Navy will continue to build partnerships, and collaborate across the defense industrial base as it develops and fields systems required to defend our nation now and in the future.

4. Bridging the gap: Advancing energy as a key performance parameter

> *"Energy is a key enabler of joint military capabilities, and ensuring the availability of sufficient energy supplies will only grow in importance with the development of new energy intensive capabilities designed to sustain and enhance warfighting capability. Distributed operations and contested logistics will challenge the sustainment of combat forces and place a premium on capabilities with longer range, time on station, endurance, and the ability to adapt to evolving energy needs and technology.."*
>
> Hon. Kathleen H. Hicks
> U.S. Deputy Secretary of Defense (DEPSECDEF)
> Memorandum for Secretaries of the Military Departments, 21 April 2022

The Department of Defense (DOD) recognizes that energy measurement is critical to understand a technology's vulnerability to fuel logistics issues. To this end, DoD implemented an energy key performance parameter (eKPP), required by statute. The Joint Requirements Oversight Council first implemented the energy Key Performance Parameter (eKPP) 2017 and incorporated the parameter within the streamlined Joint Capabilities Integration and Development System (JCIDS) process in 2018. eKPPs have been defined by the military Service sponsors when needed using energy supportability analysis to balance the energy performance of warfighting systems with the provisioning of energy inside threat environments. Over the past five years, energy supportability analysis has been shaped by different factors to include context of the unit of maneuver, energy sources of supply, future force structure, and adversary actions. Notwithstanding, a recent DoD assessment of 44 programs "found an inconsistent application" of the energy Key Performance Parameter (KPP) and "an uneven prioritization of energy supportability across joint programs" (Hicks, 2022).

Recent guidance provided by the U.S. Deputy Secretary of Defense (DEPSECDEF) aimed at aligning DoD capabilities with the 2022 National Defense Strategy. The Deputy Secretary of Defense has now directed the Chairman of the Joint Chiefs of Staff (CJCS) and the Joint Requirements Oversight Council (JROC) to include requirements for energy supportability, energy reduction and use of the energy KPP in recurring strategic guidance. The guidance also stipulates that the new requirements to enable the Joint Warfighting Concept should include energy supportability considerations whenever possible.

Figure 3: Energy Key Performance Parameter Strategic Approach

The U.S. Navy is refining the eKPP to be used across all programs to address energy consumption in future acquisition programs (Figure 3). In addition to initiatives aimed at future programs, the US Navy is currently reviewing existing weapons programs, modernization efforts and development programs in the context of energy supportability. The U.S. Navy is conducting these reviews with the purpose of providing insight on how fuel and power demands, opportunities for demand reduction, and energy supportability risks were assessed during initial system concepts, analysis of alternatives, development and fielding or any modernization efforts.

5. Conclusion

The foundation for all warfighting is the availability of sufficient operational energy, the energy required for training, moving, and sustaining military forces and weapons platforms. As such, the design and integration of operational energy is a primary focus for the US Navy. Navy Leadership must meet the challenges of today's contested environment and that of the future fight by ensuring the availability of operational energy. To help meet these objectives, the US Navy has committed to reducing energy demand, increasing platform resiliency, leverage alternative energy sources and develop new revolutionary operational strategies. Similarly, the US Navy is working to fully integrate energy considerations into operational command and control, enable assured sea control and power projection from the homeland and across the inter-theater, strengthen sustainment for distributed operations, and improve lethality.

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