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Electrical Energy Storage Strategy to Support Electrification of the Fleet

Van Bossuyt, Douglas; Oriti, Giovanna; Giachetti, Ronald E.

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ELECTRICAL ENERGY STORAGE STRATEGY TO SUPPORT ELECTRIFICATION OF THE FLEET

EXECUTIVE SUMMARY

Principal Investigator (PI): Dr. Douglas Van Bossuyt, Systems Engineering (SE)

Additional Researcher(s): Mr. Ross Eldred and Mr. Jonathan Lussier, SE

Student Participation: Mr. Daniel Camp, CIV, SE; Mr. Nathan Vey, CIV, SE; Mr. Paul Kylander, CIV, SE; Mr. Sean Auld, CIV, SE; and Mr. Jerald Willis, CIV, SE

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Topic Sponsor Name(s): Mr. Cayle Bradley
Topic Sponsor Contact Information: cayle.a.bradley1@navy.mil, (703) 614-0184

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Project Summary

Lithium-ion (Li-ion) batteries have begun to proliferate across the U.S. Navy fleet, commercial shipping, and in many other naval contexts. Naval engineers must account for Li-ion batteries when designing new vessels to ensure safety and adequate integration of the batteries into ship electrical systems. This research examines current Li-ion battery use and predicts battery requirements for the U.S. Navy's operating force in 2035 and 2045 from a mission engineering perspective and surveys key topics, including battery chemistry, energy density, charge/discharge rate and safety concerns. Projections of future battery requirements for the operating force in 2035 and 2045 are developed, highlighting the likelihood that several classes of ships will have significant growth in Li-ion batteries stored aboard in the future fleet. The role of Li-ion batteries, however, will likely be limited to running specific subsystems or equipment and will not replace ship generators. This limitation will remain true until the energy density of battery technology can compete with petrochemicals, a capability which, if even possible, is many years away. Finally, a software tool, developed in Microsoft Excel, is presented to aid in the prediction of future Li-ion storage requirements in the fleet.

Keywords: *Lithium, Lithium-Ion Batteries, Li-ion, energy storage, electrification of the fleet, directed-energy weapon, DEW, high-energy laser, HEL, hybrid electric drive, HED*

Background

The design, development, and fielding of new and emerging technologies onto Navy vessels is driving an increase in power requirements. The Deputy Chief of Naval Operations Warfare Systems (N9) office requires research be conducted to assess the current employment of lithium-ion batteries within the fleet and to aid in determining future battery requirements to power a wide variety of vehicles, weapons, and other systems. To achieve this objective, five systems engineering capstone students augmented the efforts of three department faculty members to conduct the research. Li-ion technology has quickly become the power source of choice for systems that have large, instantaneous and/or continuous power needs, and the Navy currently expects that Li-ion battery technology will continue to be needed to support many future systems. This research is intended to inform the Department of the Navy of the current state of Li-ion battery use and to substantiate requests to secure more resources to appropriately equip the fleet through 2045.

The focus of this study is battery technology aboard major U.S. Navy surface combatant ships. Small Navy vessels, submarines, supply and transport ships are not included in this study, despite potential for a Li-ion footprint. The team searched open-source and unclassified government publications, journal articles, news articles, publicly available product specifications, and other online sources. These sources were, however, somewhat limited, due to the sensitive nature of many systems currently using Li-ion battery technology.

To assess the current use of batteries in the fleet, and to predict the future growth of battery use to inform future ship construction and systems integration planning, the authors divided the effort into four parts. First, the authors identified Li-ion battery systems currently used in the fleet and key aspects of their implementation, including the location of the batteries and any available specifications, such as capacity, voltage, and intended use. Second, the team attempted to predict future battery use in both the mid-term (2030) and far-term (2045). This included considering vehicles and subsystems that are not currently battery powered but could be within these timeframes, based on predicted future Navy force structure; thus, the combination of the systems that could use batteries and the total number of systems provided a basis for the prediction of battery use in the future Navy. Third, the team considered the tradeoffs between energy generation and storage based on the requirements derived from the future fleet structure, highlighting the strengths and weaknesses of both. Finally, the team assessed future battery use across the fleet in the mid and far term, based on the future fleet structure and the trade space analysis, and presented a software tool to aid future research.

Findings and Conclusions

The research supported the original assumption that Li-ion battery technology will play an increasing role in the electrification of the fleet. The energy density of Li-ion batteries, in contrast to petrochemicals, is a long way from serious consideration as an option for ship propulsion; however, there is a significant role for Li-ion in powering mission-related systems and vehicles from a host vessel. The key challenge with estimating the exact quantity of Li-ion batteries that must be stored on future platforms is the unknown rate of Li-ion technology growth. Li-ion has experienced exponential growth in both general prevalence and improvement to its energy density since 2008, but it is expected that this growth will plateau at some point in the relatively near future.

Key considerations for shipboard Li-ion battery integration include the risks associated with thermal runaway and fire. For years, many small, unaccounted Li-ion batteries, such as those used for personal mobile phones, laptop computers, and battery backups for small electronics have been carried aboard Navy ships, while other Li-ion batteries, such as those used in missiles and sonobuoys, have been subjected to formal review processes even though they may be smaller or less of a fire risk. Loss of life or ship due to an uncontrolled thermal runaway is likely the greatest risk posed by Li-ion batteries; however, it is unrealistic and unnecessary for the Navy to monitor and control every Li-ion battery that finds its way aboard a naval vessel. Consideration should be given to the battery's intended use and storage location, including its proximity to critical systems.

Li-ion is here to stay, and continued investment in Li-ion battery technology will, among other things, support the improvement of its energy density—thereby making Li-ion batteries even more applicable for future integration use cases. Continued investment in fire suppression, packaging and handling processes will help the Navy integrate the latest battery technology while minimizing risk to platforms and sailors. Perhaps most importantly, careful planning must be undertaken in future ship designs to account for the space (and other logistic) requirements borne of the ever-increasing demand for lithium-based energy storage. The use of specially-tailored software tools, such as the one provided in this study, may aid in the effectiveness of future designs and deliberate risk planning efforts, and should be regularly updated with the most current data to maximize the tool's utility.

Recommendations for Further Research

Although the lithium-ion (Li-ion) battery shipboard integration estimation tool developed in Microsoft Excel in support of this research effort sufficiently organized the available data, updated data collected from subject matter experts in the specific technologies using lithium-ion batteries for naval applications should be inputted before the results are used to inform any major integration decisions. This study used available open-source data, but more accurate or current data may alter the trends presented in the summary. As was suggested in the final report, there are many other software packages that could be used to build a similar tool, including better database-management options such as Microsoft Access, Structured Query Language, or Mongo Database, even following the same design; however, most anticipated users are unlikely to be familiar with or have access to these databases software tools, hence the choice to use Microsoft Excel.

The team is aware of some previous efforts to capture Li-ion use in the fleet. It is recommended that future efforts capture the data elements necessary to populate this tool, as the incorporated metrics are the most salient for informing decisions regarding the implementation and adoption of Li-ion batteries when considering the risks to a particular ship. The team also recommends that the tool be extended to account for individual ships via another lookup table to delegate the platform-to-ship association to each ship's commander. Any ship may contain different platforms based on an assigned mission, so its Li-ion energy storage may vary by mission in addition to varying by the timeframe. If successful in implementation at the ship level, the Navy may consider implementing tools based on storage or use-location onboard a ship.

Understanding the general number and capacity of Li-ion batteries onboard a ship is a good starting point, but the fire risk also associated with their proximity to one another—aggregate storage—is also a very significant factor. Naval engineers should understand the risks associated with Li-ion battery storage and how those risks may affect future designs; however, legacy ship designs will remain prevalent in the modern Navy and must be considered. Likewise, future platforms will be brought onboard ships that were not initially designed to carry/service them. Basic inventory-like tracking of Li-ion batteries onboard ships using a tool like such as the one presented may be helpful in platform-based risk assessments, as well as informing broad Naval policies.

Acronyms

DEW	directed-energy weapon
HED	hybrid electric drive
HEL	high-energy laser
Li-ion	lithium-ion