Emerging Energy Technology and the Future Fight in the Indo-Pacific

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BLUF: Warfare is evolving in the Indo-Pacific region, and energy is limited. The United States must discover and/or innovate viable technologies, ways to bring said technologies to scale, and evaluate emerging energy systems.

The need to invest in emerging energy technologies has been widely noted, and has seen inroads with DoD programs like the Replicator Initiative. However, it is increasingly clear that the United States must still make major progress in order to meet the requirements of future great-power conflict – in other words, to transition from the current-day situation outlined in this section to the 5-year outlook outlined in the next section. One possible explanation for why this innovation had not occurred until relatively recently draws on research by Horowitz and Schwartz, which itself draws upon prior work in game theory and qualitative research.

According to the two, classic "realist" theories of balancing assume a "monotonically increasing relationship between security threats and proliferation."[1] However, Horowitz and Schwartz have proposed that the relationship between security threats and proliferation of important conventional capabilities – such as a reconnaissance strike complex, which manifested itself in the cult of *quality over quantity* – is non-monotonic, and the relationship looks like an inverted-U. The economic explanation for this phenomenon is that when product competition is low, firms have little to no incentive to bear the costs of innovation, as there is no other firm to

[1] Michael C. Horowitz and Joshua A. Schwartz, "To Compete or Strategically Retreat? The Global Diffusion of Reconnaissance Strike," Journal of Peace Research, September 21, 2024, 2, https://doi.org/10.1177/00223433241261566.

beat. As competition increases, the benefits of innovation increases as the firm that fails to innovate will lose market share – dubbed the “escape-competition effect.” When product competition continues to increase beyond a certain point, profits and the odds of “beating” competitor firms decreases; this in turn is called the “rent-dissipation effect.”

Horowitz and Schwartz note that literature they draw from provides inspiration [...] rather than a one-to-one match, and we propose that this framework is similarly applicable to the current dynamic at play. If adversaries possess relatively little in the way of renewable energy technologies, there is little incentive to match said capability – for instance, if an adversary’s drone fleet requires recharging at least once daily, then the United States does not have a strong incentive to invest in stronger battery technology, even if said capability would be helpful. If adversaries already possessed an overwhelming capability, the United States may be comparatively better off continuing to use current energy solutions, or simply adapting to the changing strategic landscape.

For instance, although the “pivot to Asia” was initially announced by President Obama in 2011, successive National Security Strategy (NSS) and National Defense Strategy (NDS) Reports from both his and the Trump administrations identified China as a growing threat, and the NDS-22 even identified the PRC as the chief strategic competitor, but did not explicitly label it a peer adversary. In other words, the perception of superiority led to the escape-competition effect creating a disincentive for the US to seriously invest in certain capabilities. Now that the most recent reports from the Department of Defense admit that Chinese capabilities are near parity, we have seen correspondingly serious efforts at innovation and investment.

This general relationship also holds towards PRC/US drone technology in particular. The China Military Power Report notes that “the [People’s Liberation Army Air Force] is rapidly approaching technology typical of U.S. standards" in the realm of drone technology.[2] Across the Atlantic, the use of drones in the Russo-Ukrainian War has renewed US interest in novel applications drones. For instance, the Department of Defense has taken inspiration from the Ukrainian Armed Forces' usage of cheap, one-way – or "kamikaze" – drones, and has adopted the Hellscape Concept to emulate the tactical and operational advantages of sheer quantity, or *mass*, that cheap kamikaze drones can offer.[3] This case offers two examples: First, Pettyjohn (2024) notes that although Russia entered the war with "an edge in military drones," "Ukraine has consistently out-innovated Russia with commercial technologies and software, but Russian forces have quickly adapted and emulated Ukrainian successes."[4] Thus, from the Russian perspective, the rising capabilities of an adversary force compelled them to similarly innovate and match conventional capabilities. Second, as China's drone fleet catches up to that of the United States', the US has increasingly invested more capital and brainpower towards drone capabilities – once again, the escape-competition effect creating an incentive for the currently superior force to innovate and widen the gap to their competitor. Thus, it may be reasonably assumed that the US scramble to maintain its superiority over the PRC in various capabilities – whether its submarines, drone fleet, or missile technology – is ultimately grounded in the game-theoretic, escape-competition effect, which in turn may help create the policy window necessary to execute on these initiatives.

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[2] U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 60, December 18, 2024, https://media.defense.gov/2024/Dec/18/2003615520/-1/-1/0/MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA-2024.PDF.
[3] Pettyjohn, *Evolution Not Revolution*.
[4] Pettyjohn, *Evolution Not Revolution*.

Problem 1: *In the past 6 years, there has been a rapid shift in the United States' defense posture towards littoral and maritime combat, and away from desert-based counterinsurgency; this shift has demonstrated a need for new tactical capabilities with which to equip the warfighter, in line with the energy-resilience goals of the Department of Defense.*

First, the Russo-Ukrainian War continues to demonstrate the importance of drone warfare. Whereas the United States has made extensive use of drones in the past, their mission sets were limited to precision strikes, spotting, and Intelligence, Surveillance, and Reconnaissance (ISR).[5] The Ukrainians and Russians alike have demonstrated the effectiveness of cheap, commercial drones used as a one-way attack vehicle, primarily as an alternative to expensive, military drones. Another potential use-case for unarmed commercial drones are as a spotter for crewed artillery systems, which the Ukrainians have utilized to devastating effect. However, worth noting is that commercial drones like those used in Ukraine are by-and-large electric, whereas larger, long-distance stealth drones like the MQ-9 Reaper rely upon energy-dense fossil fuels like JP-8.[6] As such, a possible innovation in the short-term would be the improvement of batteries used in drones. Currently, heavier drones like the Reaper are limited in where and when they can be employed, owing to the fact that they must be refueled. By contrast, smaller drones utilizing battery power are more versatile – if these drones can be recharged on the move, their down-times would be reduced, and smaller units at the platoon-level or below could have near-constant aerial ISR capabilities. There has already been movement towards this, like with the Marine Corps' new integrated squad concept, or the

[5] Stacie Pettyjohn, "Evolution not Revolution," *Center for a New American Security* (Washington D.C.), February 8, 2024, accessed November 1, 2024.
[6] Enercon Power, "The Role of Electric Drones in Military Applications," Enercon, last modified June 12, 2024, https://www.enerconpower.com/post/the-role-of-electric-drones-in-military-applications#:~:text=In%20online%20with%20the%20development,recharge%20 drones%20on%20the%20move.

Department of Defense's Replicator Initiative, which aims to equip the armed forces with thousands of all-domain attritable autonomous systems (ADA2, or simply autonomous drones) by August 2025, with an eye towards incentivizing such innovations as in battery technology.[7]

At present, there is a series of developments already underway in incorporating, or at least further exploring, a variety of new energy technologies to enhance military operations. There are, however, some challenges to consider. This includes microgrids, renewable energy sources, vehicle-to-grid technology, battery storage, small modular reactors (SMRs), and microreactors.

Overview of Emerging Technologies:

Microgrids: Microgrids, or small, fully autonomous power grids, allow DoD bases and installations to be functionally independent from the rest of the power grid, enhancing readiness against potential attacks on the power grid. For example, the Otis Air National Guard Base uses a fully islandable microgrid combining 1.5 MW wind power, lead-acid batteries, and smart energy management, allowing uninterrupted operations even during grid disruptions.[8]

Most military bases and other federal facilities used for military purposes do not, however, use any form of microgrids, but military and civilian leaders are hoping to rapidly change that moving forwards. These grids would not, and those currently installed do not, permanently supplant the surrounding power grid that these bases and facilities are plugged into, but rather serves as a last resort during times when main sources of power are down.[9]

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[7] Department of Defense, "Replicator," Defense Innovation Unit, https://www.diu.mil/replicator.
[8] Saritas, Ozcan, and Serhat Burmaoglu. "Future of sustainable military operations under emerging energy and security considerations." *Technological Forecasting and Social Change* 102 (2016): 331-343.
[9] "The US Army Uses Microgrids to Provide Resiliency, Address Climate Change, and Control Costs," *Enerdynamics Blog*, accessed January 12, 2025,

Importantly, having a microgrid ready to provide energy is both more resilient and cleaner than current backup generators[10].

Climate considerations aside, US military bases are "almost entirely reliant on" the aging electrical grid, a situation that induces outages causing costly interruptions to training and missions far too frequently.[11] Additionally, the military spends a considerable amount of money on energy, roughly $4 billion as of 2017[12], costs that can be reduced in time with the relative cheapness of power from microgrids over stand-alone generators.

Solar & Wind: Solar and wind energy are becoming increasingly important components of military energy strategies, enhancing resilience and reducing dependency on traditional fuel supplies. For instance, the Marine Corps Recruit Depot at Parris Island operates a 6.7 MW solar array, supplying up to 79% of the base's power needs and saving $6.9 million annually.[13] Similarly, other bases, such as Nellis Air Force Base in Nevada, use large-scale solar farms to lower energy costs and increase self-sufficiency.[14]

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https://www.enerdynamics.com/Energy-Currents_Blog/The-US-Army-Uses-Microgrids-to-Provide-Resiliency-Address-Climate-Change-and-Control-Costs.aspx.

[10] Amanda Miller Tirpak, "Microgrids Keep the Power On at Overseas Air Force Bases," *Air & Space Forces Magazine*, accessed January 12, 2025, https://www.airandspaceforces.com/air-force-military-overseas-bases-microgrids-power/.

[11] Pew Charitable Trusts, "US Military Could Save over $1 Billion and Boost Energy Security, New Research Finds," *The Pew Charitable Trusts*, January 12, 2017, https://www.pewtrusts.org/en/research-and-analysis/articles/2017/01/12/us-military-could-save-over-1-billion-and-boost-energy-security-new-research-finds.

[12] Pew Charitable Trusts, "US Military Could Save over $1 Billion and Boost Energy Security, New Research Finds," *The Pew Charitable Trusts*, January 12, 2017, https://www.pewtrusts.org/en/research-and-analysis/articles/2017/01/12/us-military-could-save-over-1-billion-and-boost-energy-security-new-research-finds.

[13] Frączek, Mariusz, Krzysztof Górski, and Leszek Wolaniuk. "Possibilities of powering military equipment based on renewable energy sources." *Applied Sciences* 12.2 (2022): 843.

[14] Jeffery Blazi, "Nellis AFB Reduces Greenhouse Gas Emissions Through Solar Energy," *U.S. Air Force News*, October 26, 2021, https://www.af.mil/News/Article-Display/Article/2819757/nellis-afb-reduces-greenhouse-gas-emission-through-solar-energy/.

Currently, about 6.5% of the Department of Defense's electricity consumption is sourced from renewable energy, which is below the national average of approximately 20%. While this reflects progress, the majority of energy consumption remains heavily reliant on traditional fossil fuels.[15]

However, the intermittent nature of solar and wind energy poses challenges. Bases often rely on backup systems, like batteries or generators, to ensure continuous power during periods of low solar or wind generation.[16] Despite these challenges, the Department of Defense is prioritizing the use of renewables to improve energy independence, reduce carbon emissions, and lower operational costs.

Vehicle-to-Grid (V2G): V2G capabilities allow electric vehicles (EVs) to discharge power back into local grids during peak demand. For example, the Los Angeles Air Force Base[17] has integrated V2G-enabled EVs that support local grid stability, providing savings and operational flexibility. Such systems can be adapted for deployed forces, where vehicles serve as mobile power sources in combat zones, reducing reliance on fuel convoys.

Outside of a handful of situations, however, V2G technology is not being widely used for military purposes. For starters, not every EV, hybrid electric vehicle (HEV), and plug-in electric vehicle (PEV) provides for bidirectional charging, so there is a more limited set of vehicles that

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[15] Theresa Hitchens, "Why the US Military Should Build Modular Nuclear Reactors," *Defense News*, March 16, 2023, https://www.defensenews.com/opinion/commentary/2023/03/16/why-the-us-military-should-build-modular-nuclear-reactors/.

[16] U.S. Department of Energy, "Energy Efficiency and Renewable Energy," accessed January 12, 2025, https://www.energy.gov/eere.

[17] Ducey, Roch A., et al. "Control dynamics of adaptive and scalable power and energy systems for military micro grids." (2006).

consumers, and the military, can purchase to acquire V2G capabilities.[18] Additionally, facilities need bidirectional charging stations as well, which they are not currently mandated to include.[19]

Battery Storage: Battery Energy Storage Systems (BESS) play a critical role in enhancing energy resilience at military installations. Fort Carson's 4.25 MW/8.5 MWh lithium-ion storage system showcases how batteries enable peak saving, integrate renewable energy, and ensure backup power during outages. This system exemplifies how BESS can reduce dependency on fossil fuels and ensure operational continuity during grid disruptions ("A Review on Energy Storage Systems and Military Applications" "Lithium-Based Batteries in Tactical Military Applications: A Review").

Tactical energy storage, such as Tactical Energy Storage Units (TESUs), provides silent, portable power solutions for forward operating bases (FOBs). TESUs minimize logistical risks by reducing reliance on fuel convoys, a vulnerability in conflict zones ("A Systems Approach for Analyzing Operational Energy Requirements for the Warfighter,"). Despite their effectiveness, current battery technologies face challenges such as high costs, weight constraints, and limited performance in extreme conditions ("Lithium-Based Batteries in Tactical Military Applications: A Review,").

From an economic perspective, the initial capital outlay for BESS is substantial, but life cycle cost analyses reveal significant savings in operational and logistical expenses. Reducing fuel dependency not only minimizes supply chain vulnerabilities but also lowers carbon emissions, aligning military operations with broader sustainability objectives ("Survival of the

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[18] "Bidirectional Charging and EVs: How Does It Work and Which Cars Have It?" *CNET*, accessed January 12, 2025, https://www.cnet.com/home/electric-vehicles/bidirectional-charging-and-evs-how-does-it-work-and-which-cars-have-it/.

[19] AFRY, "Vehicle-to-Grid Infrastructure Buildout in the United States: Pipe Dream?" accessed January 12, 2025, https://afry.com/en/insight/vehicle-grid-infrastructure-buildout-in-united-states-pipe-dream.

Greenest").

SMRs: Small Modular Reactors (SMRs) offer a scalable and reliable energy solution for military bases. Their capacities, ranging from 10 MW to 300 MW, are well-suited for the energy demands of military installations. SMRs' modular designs enable incremental deployment, ensuring adaptability to varying energy requirements ("Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications," ; "The Feasibility of Small Modular Reactors for Military Installations,").

One significant advantage of SMRs is their passive safety features and long operational cycles, with some designs requiring refueling only every 10 years. The Hyperion Power Module, for instance, highlights the potential of factory-sealed, truck-transportable reactors for remote installations. Additionally, SMRs can support dual-use applications such as water desalination or hydrogen production, increasing their strategic value ("The Feasibility of Small Modular Reactors for Military Installations,"; "Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications,").

However, challenges such as high first-of-a-kind (FOAK) costs, lengthy regulatory processes, and site-specific considerations hinder widespread deployment. The Clinch River SMR project illustrates both the promise and complexity of integrating these systems into military operations ("Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications,"). Economic modeling indicates that cost-sharing frameworks between public and private entities could accelerate adoption ("Innovation Policy and International Relations,").

Microreactors: Microreactors, with outputs of 1 MW to 10 MW, are designed for rapid deployment and mobility. These compact systems are factory-assembled and optimized for remote and forward-deployed bases. Their ability to operate independently of grid infrastructure makes them particularly valuable in austere environments ("Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications").

Microreactors' passive safety features and reduced logistical requirements ensure reliability and flexibility. Their compatibility with hybrid energy configurations, integrating renewables and battery storage, enhances their adaptability to diverse military missions ("The Feasibility of Small Modular Reactors for Military Installations"). However, concerns regarding security, licensing, and public perception present significant challenges ("Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications").

Problem 2: *Furthermore, the DoD's shift towards the Indo-Pacific has also necessitated new research and development of new energy systems to enable these new kinds of weapons and initiatives. We examine how these emerging systems can be made militarily operational.*

Recommendation: Vehicle to grid tech, microgrids, lasers/directed-energy, SMRs.

Currently the use of directed energy weapons – colloquially, laser technology – is highly limited, and likely to be so "for the foreseeable future because of their large energy needs, limited range and problems with bad weather. But militaries say the new weapons could prove an effective way to shoot down drones, a key task as they look for cheaper ways to counter a proliferation of unmanned aerial vehicles in combat."[20] Over the last two decades, the field of

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[20] Alistair MacDonald, "Why Lasers Could Be Kryptonite for Drones," The Wall Street Journal (New York City, NY), October 14, 2024, https://www.wsj.com/business/why-lasers-could-be-kryptonite-for-drones-88e4cd4e.

directed energy weapons has seen drastic improvements – one such example is the adoption of fiber lasers as opposed to chemical or gas-based lasers.[21] The changing battlefield – marked by innovations like the widespread adoption of drones – also provides a new use-case, whereas previously these lasers were a solution in search of a problem. In particular, the high energy demand of these weapons indicates that efficient and mobile energy sources like more powerful batteries would enable the disaggregated usage of directed energy weapons, perhaps as a counter to hostile unmanned aerial vehicles. For instance, advancements in mobile energy infrastructure may mean that directed energy weapons could be deployed as a company or battalion-level asset attached to Air-Defense-Artillery (ADA) units, thus screening against enemy air superiority in much the same way ADA units currently protect ground troops and assets against manned enemy air capabilities. Alternatively, they could be used as anti-aircraft/missile defense measures on-board larger vessels fueled by nuclear reactors like aircraft carriers, functioning in much the same way that CWIS systems do. In sum, this is an identifiable area in which the DoD can easily capitalize on existing technologies and create new synergies to give warfighters at the squad level greater assets to counter an evolving threat landscape.

Energy resilience and security remain core priorities for DoD as it adapts to an increasingly complex global energy landscape. In the medium term, DoD is poised to make strategic investments that build upon the short-term advances outlined in the previous section. For example, while short term policy projection highlights the immediate deployment of microgrids to increase operational autonomy during grid outages, the medium term will see these systems evolve into more integrated, scalable networks capable of managing a diverse portfolio of renewable energy sources. These enhanced microgrids will incorporate artificial intelligence-driven energy management systems to optimize energy distribution across

[21] MacDonald, "Why Lasers."

installations, thereby improving resilience against cyberattacks and disruptions. Such developments tie directly to the short-term initiatives by expanding beyond foundational implementations to create a robust, fully networked energy system that supports broader mission sets. This shift underscores the DoD's commitment to advancing technologies that not only secure installations but also increase operational flexibility and efficiency (10 U.S.C. § 2911(b)).

One of the DoD's cornerstone programs for achieving this vision is the Energy Resilience and Conservation Investment Program (ERCIP). Over the medium term, ERCIP will drive targeted projects aimed at upgrading energy infrastructure with next-generation technologies. For instance, while Section 1 may focus on the initial rollout of renewable energy systems, the medium term will emphasize their integration with large-scale energy storage solutions, ensuring uninterrupted operations even in contested environments. The recent $636 million allocation for ERCIP in FY 2025 highlights the scale of these investments and reflects a deliberate effort to address vulnerabilities identified in the short term, such as the reliance on centralized power grids and aging infrastructure. Through these initiatives, the DoD aims to fortify installations against not only physical and environmental threats but also cyberattacks, which are an increasingly prominent concern as energy systems become more digitized[22].

The medium-term policy will build upon the short-term focus on operational energy independence by incorporating advanced nuclear technologies, including SMRs, to address DoD's growing energy needs. SMRs, which are compact and scalable compared to traditional nuclear reactors, are particularly advantageous for their ability to be deployed quickly and efficiently. Their modular design enables incremental energy capacity expansion, allowing installations to tailor energy solutions to their specific requirements. Unlike renewable energy

[22] U.S. Department of Defense, Office of the Under Secretary of Defense (Comptroller). *National Defense Budget Estimates for FY 2025 (Green Book).* Washington, DC: Department of Defense, 2024. https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2025/fy25_Green_Book.pdf.

sources like solar and wind, which are subject to intermittency, SMRs provide continuous, carbon-free power, making them a dependable solution for critical operations. This reliability is especially crucial for forward-deployed bases and remote installations, where access to external energy supplies may be limited or compromised. One notable project planned for the medium term is the deployment of an SMR at Joint Base San Antonio. This initiative exemplifies the DoD's approach to bridging the gap between short-term gains in renewable energy adoption and medium-term goals of enhancing energy resilience. The SMR will serve as a reliable, autonomous power source, ensuring that mission-critical systems remain operational even in austere environments. By reducing reliance on fuel convoys and external energy grids, the deployment of SMRs addresses logistical vulnerabilities, enhancing the energy independence of installations. Furthermore, SMRs can operate alongside renewable systems, creating a hybrid energy model that maximizes system efficiency and resilience.

In addition to their reliability, SMRs offer significant cost and logistical benefits over traditional energy sources. Their ability to be factory-built and transported to sites minimizes construction costs and time, allowing for rapid deployment in medium-term planning horizons. These reactors are designed with advanced safety features, further reducing risks associated with nuclear energy and making them viable for both domestic and forward-operating locations. However, challenges remain, including the need to navigate regulatory approvals and address public perceptions regarding nuclear energy. By addressing these hurdles, the DoD can position SMRs as a cornerstone of its medium-term energy strategy, ensuring that installations are equipped to meet evolving energy demands in a secure and sustainable manner. By 2030, these medium-term efforts will significantly advance the department's goals of energy security and operational effectiveness.

Microgrids: There are plans to expand the use of microgrids in the medium term. Namely, GSA and DoD are looking for carbon-free energy at federal facilities (in mid-Atlantic and Midwest) by 2030 given that the DoD in particular uses massive amounts of energy.[23] Progress on installing microgrids in all military bases will continue to take time, but goals to do so in all 130 bases worldwide by 2035[24] will continue to move along.

Solar & Wind: In the next five years, military efforts to expand solar and wind energy deployment will focus on optimizing their use in diverse environments. Bases located in areas with consistent sunlight or wind patterns will increasingly adopt these technologies to reduce their reliance on fossil fuels. For example, Fort Hood in Texas has already implemented a large-scale renewable energy project combining on-site solar arrays and an off-site wind farm to cover 45% of the base's energy needs[25].

Additionally, advances in energy storage technology will address the intermittency of wind and solar energy. Bases are expected to integrate more robust battery systems to store excess energy, ensuring a reliable power supply during peak demand or adverse weather conditions. This expansion of renewable capacity will support more remote and forward-operating bases, reducing the logistical challenges associated with transporting fuel to these locations.

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[23] Dave Kovaleski, "Daily Energy Insider - Macallan Communications: GSA, Defense Department Seeking Contractors to Provide Clean Energy," ABI/INFORM Global; Agricultural & Environmental Science Collection (blog), 2024.

[24] "Army to Equip All Bases with Microgrids by 2035 as Part of Carbon-Free Electricity Goal," *Microgrid Knowledge*, accessed January 12, 2025, https://www.microgridknowledge.com/editors-choice/article/11427449/army-to-equip-all-bases-with-microgrids-by-2035-as-part-of-carbon-free-electricity-goal.

[25] American Association for the Advancement of Science (AAAS), "Fort Hood Embraces Renewable Energy; Other Military Posts Follow Suit," accessed January 12, 2025, https://howwerespond.aaas.org/fort-hood-embraces-renewable-energy-other-military-posts-follow-suit.html.

Vehicle-to-Grid (V2G): To accomplish noticeable V2G adoption in the medium-term, the federal government must enact sustaining requirements to install bidirectional charging stations at military facilities, otherwise any investment in vehicles will not go without results. Given the cost of these ports relative to single-direction ports and the relatively limited options available[26], this likely cannot be seen through immediately but can easily be accomplished in a reasonable time frame.

Secondly, continued subsidies for all varieties of EVs will shift the auto sector toward greener technology, boosting competition in the industry that will in turn decrease prices for consumers, including the US military.[27]

Battery Storage: In the next five years, advancements in lithium-ion and solid-state batteries are expected to address existing limitations. Investments in R&D will focus on increasing energy density, improving temperature resilience, and reducing costs. Training personnel in maintaining and operating these systems will ensure broader adoption at both permanent and forward-deployed installations ("A Systems Approach for Analyzing Operational Energy Requirements for the Warfighter" "A Review on Energy Storage Systems and Military Applications").

Hybrid systems combining batteries with solar and wind power will further reduce logistical burdens and support the Department of Defense's (DoD) energy efficiency goals ("A Review on Energy Storage Systems and Military Applications"). Economically, this transition

[26] *Top Gear*, "What Is Bi-Directional Charging, and Which Cars in the UK Can Support It?" accessed January 12, 2025, https://www.topgear.com/car-news/tech/what-bi-directional-charging-and-which-cars-uk-can-support-it.
[27] Kim Lyons, "Inflation Reduction Act: How the Climate Law Set a Trillion-Dollar Shift for EVs into Motion," *Yahoo Finance*, August 2023, https://finance.yahoo.com/news/inflation-reduction-act-how-the-climate-law-set-a-trillion-dollar-shift-for-evs-into-motion-155615359.html.

enables greater reliance on renewable resources, offsetting operational costs while enhancing mission resilience ("Survival of the Greenest").

SMRs: Within the next five years, pilot SMR projects will provide valuable insights into their economic and operational feasibility. Streamlining the Nuclear Regulatory Commission (NRC) licensing process and adopting cost-sharing models will be essential to overcoming FOAK barriers. Advances in modular construction and safety features will further enhance SMRs' adaptability ("The Feasibility of Small Modular Reactors for Military Installations,"; "Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications,").

The DoD should prioritize deploying SMRs at high-priority installations vulnerable to grid disruptions. These systems will provide energy security and reduce dependency on fossil fuels, aligning with the DoD's sustainability objectives ("Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications,"). Economically, SMRs promise long-term cost savings by eliminating fuel supply chain vulnerabilities and enabling stable energy costs ("Innovation Policy and International Relations").

Microreactors: In the medium term, demonstration projects will validate microreactors' performance in diverse scenarios. Enhancements in portability, safety, and modularity will enable broader deployment. Hybrid configurations will allow microreactors to seamlessly integrate with renewable energy systems, providing scalable and mission-adaptive solutions ("The Feasibility of Small Modular Reactors for Military Installations"; "Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications").

The DoD should prioritize developing advanced microreactors tailored to tactical needs, ensuring rapid deployment and operational resilience in contested environments ("Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications"). Economic analyses suggest that their deployment could lower operational costs by reducing reliance on traditional fuel logistics, enhancing cost-effectiveness ("Survival of the Greenest").

Problem 3: *In the long run, the United States must implement a variety of energy sources and systems in order to create redundancy on the operational scale.*

In the long–term horizon, the US may need to implement a purposeful mix of energy sources necessary to ensure resilience and redundancy of the technology of the warfighter. Different types of bases, weapons, and systems will need various mixes of power, correlated to their capabilities. Small drones can rely on standalone battery packs, with certain onsite generation systems that allow batteries to be quickly recharged. This could include systems like solar arrays, or more portable devices such as microreactors. Large drones would require more complicated charging solutions, such as advanced liquid fuels or hydrogen based solutions. This requires more infrastructure such as the refinement of energy, storage, and logistics. Extending discussion to counter-drone systems, while typically stationary, these technologies would have high peak loads, which necessitates a more stable baseload power.

Potential mobile energy sources include portable reactors that allow the military to use this pivotal technology in a non-restrictive location.[28] Further developing these self-sustaining technologies extends the capabilities of the warfighter beyond the physical base supply chains,

[28]https://www.dla.mil/About-DLA/News/News-Article-View/Article/3842532/dods-need-for-a-transportable-energy-solution-the-promise-of-nuclear-power/

and enhances operational independence.[29] Fixed installations, referring to American bases, can benefit from further refinement of their baseload powers that can supplement the current grid infrastructure that they run on. The electrification and integration of more complex digital infrastructure within the warfighter also raises the importance of cybersecurity measures. With many vehicles and machinery incorporating onboard navigation and control systems, the potential threat of an adversary using digital warfare as a manner of disrupting the operations of the warfighter must be preemptively protected against. Cyber attacks targeted at smart, unmanned, or hybrid machinery is likely possible due to the digitization and extensive use of onboard software.

Potential ways to combat these new forms of warfare include "Security by design", entailing integrating cybersecurity within the very design of all infrastructure or vehicles. This ensures proper encryption, data usage, and cybersecurity protocols are followed.[30] Another emerging technology is red teaming, or using ethical hackers to test systems, includes penetration testing, bug bounties, etc. Finally, it is of utmost importance that all stakeholders secure data, as through the flow of information from server to vehicle, ensuring that any chinks in the armor of encryption are not exposing flaws for hackers to use as entry points. As a point of proof for these necessary technologies, Russia has launched multiple attacks against the Ukraine cyber grid, showing how adversaries seek to use control systems and data acquisition (ICS/SCADA) systems as targets for cyber attacks.[31]

3.2: What are the strategic implications of this long-term vision?

With regard to direct strategic competitors, particularly in strategic energy chokepoints,

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[29] ICHORD, ROBERT F., and JENNIFER T. GORDON. "Innovation in Nuclear Energy Technologies: Implications for US National Defense." Atlantic Council, 2020. http://www.jstor.org/stable/resrep25998.
[30]https://warontherocks.com/2024/06/power-and-tension-the-cyber-security-problems-of-military-electrification/
[31] https://www.afcea.org/signal-media/cyber-edge/us-military-must-defend-its-power-grid

we can look towards Chinese rhetoric around technological development. In 2017, Xi Jinping said "Under a situation of increasingly fierce international military competition, only the innovators win." The same year, China announced in its New Generation AI Development Plan its ambition to become a global leader in science and technology by 2030. By 2023, Beijing formally announced it would be advancing its research and development across a wide range of emerging technologies, including artificial intelligence (AI), quantum information science, hypersonics, biotechnology, semiconductors, 5G, and aerospace. These fields were all marked as critical for military-civilian integration in the country's 2021 Five-Year Plan, which also set long-term goals for 2035. China's domestic research institutions now lead in outputs across several of these domains, potentially positioning China as a global technological leader and posing competitive challenges for other nations, namely the United States. In addition, it continues to pursue anti-access and area-denial capabilities in direct competition and rivalry with the US and its allies.

To combat China's pursuit of modernization in the People's Liberation Army (PLA) on 3 fronts by 2027, the US would need to tackle the following: Mechanization: Equipping forces with advanced platforms, such as modernized armored vehicles and electronic warfare systems, a goal the PLA had largely achieved by 2020 after decades of effort. Informatization: Securing "information dominance" by enhancing cyber and space capabilities, linking systems to networks, and enabling precision, long-range, and unmanned warfare. This focus on informatization has been a priority since the 1990s to enhance PLA's capacity in local, high-tech conflicts. Intelligentization: Developing autonomous, intelligent systems with technologies like AI, quantum computing, and big data, aimed at maintaining technological parity with global competitors.

Civilian nuclear power sector should be included as part of US national security; the military cannot operate as a stand alone entity. As global demand for energy continues to increase at an exponential rate, many countries around the globe are becoming increasingly dependent on oil from the Middle East, which could be easily disrupted. For the warfighter, it will be crucial to not be reliant on such countries that could expose vulnerabilities in times of geopolitical instability. In its place, the military should seek alternative energy sources to enhance military resilience. Currently, in "FY22, the DoD consumed over 73 million barrels of fuel to support worldwide operations and training. Reflecting the Department's worldwide operating footprint, 48% of this energy was purchased outside of the U.S."[32] Even though global natural gas production is increasing, sustainability warrants that alternative sources of power such as nuclear, solar, wind, biomass, or geothermal, must also be further developed towards an inflection point. This depends on the economics of each individual renewable energy source, as in most nations the market remains king, and until these alternatives develop similar cost structures to traditional fossil fuel resources. Reliance on fossil fuels could render nations more susceptible to energy markets and any geopolitical instability. In this, collaboration between civilian sectors and military is essential, because military investments can drive energy innovation and help support R&D spending, making the scale necessary for renewables to be economically more viable. Especially given that the US maintains one of the largest and most dominant private sectors, the nation should leverage the American advantage of being a market for competitiveness. In turn, this should allow the military to gain a first-mover's advantage to these new and emerging technologies. This continual relationship between civilian and military must be at the forefront of development to continue strengthening the geopolitical position of the US.

[32] https://www.acq.osd.mil/eie/eer/oe/index.html

On the large scale, some general operational priorities should include: Upscaling current workforce for military personnel focusing on weapons technicians, pilots, energy specialists, etc., as well as maintenance personnel and operations; Streamlining licensing for new commercial power technologies, further accelerating the growth and development of energy tech in the American market; Strengthen alliances to share technology and create transferable energy infrastructure, maintaining strategic edge.

Microgrids: Plans to expand microgrids will make the most impact in the long-term. The US Army will have completed plans to install a microgrid at all 130 of its bases worldwide by 2035[33], in line with its 2020 energy and water plan to enhance its resilience. Further, the Army plans to incorporate microgrids into its "contingency bases" by 2050, which are currently very dependent on fossil fuels.[34]

The cost benefits for microgrids are clearest in the long-run as well. Over a 20-year time frame, the US military could save anywhere from $8 million to $20 million per base, resulting in potentially over a $1 billion saved by replacing all of the current and widespread stand-alone generators.[35] As the costs for battery storage and solar technologies intertwined with microgrids

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[33] "Army to Equip All Bases with Microgrids by 2035 as Part of Carbon-Free Electricity Goal," *Microgrid Knowledge*, accessed January 12, 2025, https://www.microgridknowledge.com/editors-choice/article/11427449/army-to-equip-all-bases-with-microgrids-by-2035-as-part-of-carbon-free-electricity-goal.

[34] "Army to Equip All Bases with Microgrids by 2035 as Part of Carbon-Free Electricity Goal," *Microgrid Knowledge*, accessed January 12, 2025, https://www.microgridknowledge.com/editors-choice/article/11427449/army-to-equip-all-bases-with-microgrids-by-2035-as-part-of-carbon-free-electricity-goal.

[35] Pew Charitable Trusts, "US Military Could Save over $1 Billion and Boost Energy Security, New Research Finds," *The Pew Charitable Trusts*, January 12, 2017, https://www.pewtrusts.org/en/research-and-analysis/articles/2017/01/12/us-military-could-save-over-1-billion-and-boost-energy-security-new-research-finds.

also drop, it is entirely possible that these savings will be even greater as the cost of supplying and maintaining microgrids decreases.[36]

Solar & Wind: Over the next decade, solar and wind energy are projected to become primary energy sources for military installations worldwide. The decreasing cost of solar panels and wind turbines, coupled with advancements in energy storage and smart grid technologies, will make renewables more economically viable and operationally efficient.[37] By 2035, the military aims to power most installations with renewables, reducing greenhouse gas emissions and strengthening energy resilience. Remote and forward-operating bases are expected to fully transition to hybrid systems that integrate solar, wind, and advanced storage solutions. These systems will enable sustained operations in hostile or remote environments without reliance on vulnerable supply chains.[38] In the long run, renewables' role in military strategy will extend beyond installations to include combat scenarios. Portable solar and wind systems, combined with high-capacity storage, could provide on-demand energy for deployed forces, powering equipment, communications, and other mission-critical systems. This transition will not only improve operational efficiency but also enhance the military's ability to adapt to climate challenges and geopolitical uncertainties.

Vehicle-to-Grid (V2G): In the long run, V2G technology can be incorporated to fully overhaul the US military's fuel usage. Not only can V2G tech stabilize the grid during power surges and

[36] "The US Army Uses Microgrids to Provide Resiliency, Address Climate Change, and Control Costs," *Enerdynamics Blog*, accessed January 12, 2025, https://www.enerdynamics.com/Energy-Currents_Blog/The-US-Army-Uses-Microgrids-to-Provide-Resiliency-Address-Climate-Change-and-Control-Costs.aspx.
[37] "The U.S. Army Commits to Using 100% Clean Electricity by 2030," *PV Magazine USA*, February 10, 2022, https://pv-magazine-usa.com/2022/02/10/the-u-s-army-commits-to-using-100-clean-electricity-by-2030/.
[38] U.S. Army, "Army Introduces Strategy to Combat Climate Change Threats," *U.S. Army Official Website*, February 2022, https://www.army.mil/article/253863/army_introduces_strategy_to_combat_climate_change_threats.

emergencies, but full adoption of this technology can also lead to mobile power units in forward-operating bases and combat zones, reducing reliance on fuel convoys.[39] Additionally, V2G allows the military to use vehicles as temporary storage systems, reducing reliance on traditional battery storage and grid power[40], and removes a significant amount of dependency on fossil fuel supply chains, especially in remote and conflict-ridden areas where fuel delivery can be difficult and dangerous.[41]

Battery Storage: In the long term, battery storage will dominate military energy infrastructure. Solid-state and flow batteries will likely achieve breakthroughs in capacity and lifecycle, enabling installations to operate with near-complete energy autonomy. Universal deployment of advanced BESS across DoD facilities will support zero-emission operations and enhance energy resilience ("Lithium-Based Batteries in Tactical Military Applications: A Review"). Strategic partnerships with private sector innovators and international collaborators will be critical to maintaining technological leadership ("Survival of the Greenest").

SMRs: By 2035, SMRs are projected to become a key player of military energy strategy. Their scalability and autonomy will support permanent installations requiring high energy reliability. Long-term success will depend on addressing nuclear waste disposal, public acceptance, and integrating SMRs into broader energy infrastructures ("The Feasibility of Small Modular Reactors for Military Installations"). Economic spillovers, including job creation and localized

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[39] "Distributed Energy Resource Management: Military Microgrids and Tactical Applications," *IEEE Explore*, accessed January 12, 2025, https://ieeexplore.ieee.org/document/8125782.
[40] "Distributed Energy Resource Management: Military Microgrids and Tactical Applications," *IEEE Explore*, accessed January 12, 2025, https://ieeexplore.ieee.org/document/8125782.
[41] U.S. Army, "Vehicle Power Networks to Provide More Combat Lethality," *U.S. Army Official Website*, April 2023, https://www.army.mil/article/258621/vehicle_power_networks_to_provide_more_combat_lethality.

supply chain development, could further enhance their strategic value ("Innovation Policy and International Relations").

Microreactors: Over the next decade, microreactors are projected to be a key player in expeditionary energy strategies as well. They serve their function by providing compact, reliable power for forward bases and mobile units. Innovations in materials and safety designs will enhance their portability and resilience. Widespread adoption will depend on addressing logistical and security challenges, as well as gaining public and regulatory approval ("The Feasibility of Small Modular Reactors for Military Installations"). Microreactors' ability to support energy-intensive technologies, such as advanced communications and surveillance systems, will make them indispensable in future military operations. Their economic benefits, including reduced long-term costs, will solidify their role in military energy planning ("Innovation Policy and International Relations").

Conclusion/Comparative Analysis:

Energy Output and Reliability

Microgrids: Microgrids enhance energy reliability by allowing bases to operate autonomously during grid outages. While they are dependent on renewable or traditional energy inputs, their ability to integrate multiple energy sources makes them a robust solution for energy continuity under varying conditions.

Solar & Wind: Solar and wind are dependent on weather conditions, providing intermittent energy outputs. When paired with advanced energy storage systems, they can ensure consistent power for non-energy-intensive installations, though their reliability is contingent on geographic/climatic factors.

Vehicle-to-Grid (V2G): V2G technology enables vehicles to act as mobile power sources during outages, providing supplemental energy during peak demand. However, its reliance on bidirectional EVs and compatible charging infrastructure limits scalability and consistency for large-scale applications.

Battery Storage: While Fort Carson's lithium-ion BESS demonstrates reliability for backup power and renewable integration, its reliance on external energy inputs and limited scalability for continuous high-energy needs makes it unsuitable for installations with significant energy demands.

SMRs: With outputs ranging from 10 MW to 300 MW, SMRs are unmatched in providing consistent, large-scale energy independent of external sources. Examples like the Hyperion Power Module illustrate their capability for long-term energy reliability, ideal for permanent installations.

Microreactors: Offering 1 MW to 10 MW, microreactors fill a critical niche for remote or mobile operations. Their ability to provide reliable power under austere conditions highlights their versatility, particularly for forward bases and temporary missions.

Deployment Flexibility

Microgrids: Microgrids are semi-mobile and adaptable to both permanent installations and contingency bases. Their modularity allows them to be scaled based on energy needs, though deployment is limited by infrastructure and setup time.

Solar & Wind: Solar and wind systems are highly scalable and adaptable to diverse environments. Portable solar arrays and wind turbines enhance their deployability for forward bases, though installation time and dependency on specific conditions limit immediate flexibility.

Vehicle-to-Grid (V2G): V2G systems can be integrated into existing infrastructure with minimal modifications, offering flexible energy solutions for localized needs. However, their effectiveness depends on the availability of compatible vehicles and charging stations.

Battery Storage: The rapid deployability of systems like TESUs enhances operational flexibility in scenarios requiring silent, portable energy. However, their dependence on renewable integration limits their standalone viability in isolated settings.

SMRs: Deployment involves long planning cycles and regulatory compliance, making SMRs better suited for stable, semi-permanent installations where their modular nature can scale energy provision over time.

Microreactors: Microreactors offer unparalleled mobility among nuclear technologies. Their compact designs allow for rapid deployment to remote or forward-deployed locations, catering to expeditionary and disaster-relief operations where infrastructure is minimal.

Cost Considerations

Microgrids: Microgrids involve moderate upfront costs but offer long-term savings by reducing dependency on external power grids and fossil fuels. Their cost-effectiveness improves when integrated with renewables and storage systems.

Solar & Wind: While solar and wind energy have high initial costs, they offer significant long-term savings through reduced fuel costs and maintenance. Declining prices of solar panels and wind turbines further enhance their economic appeal for military use.

Vehicle-to-Grid (V2G): The cost of V2G systems depends on the availability of bidirectional charging infrastructure and compatible vehicles. Initial expenses are offset by savings from grid stabilization and reduced reliance on external energy sources.

Battery Storage: High upfront costs are offset by significant life cycle savings through reduced fuel logistics and maintenance. Integrating batteries with renewable systems, as seen at Fort Carson, underscores their economic efficiency in hybrid configurations.

SMRs: Despite high first-of-a-kind costs, SMRs promise substantial long-term savings by replacing fossil-fuel systems and stabilizing energy costs. Cost-sharing initiatives and advances in modular construction can mitigate initial expenses.

Microreactors: Offering lower initial costs than SMRs, microreactors improve cost efficiency by reducing reliance on traditional fuel supply chains. Their economic viability lies in localized energy production for specific mission needs.

Sustainability and Carbon Impact

Microgrids: By integrating renewables, microgrids reduce reliance on fossil fuels and contribute to carbon-neutral operations, particularly when combined with energy storage systems.

Solar & Wind: Solar and wind are inherently sustainable, producing zero emissions during operation. Their integration into military energy strategies aligns with long-term decarbonization goals.

Vehicle-to-Grid (V2G): V2G technology supports sustainability by leveraging EVs as energy storage and reducing the need for fossil-fuel-based power backups, thus contributing to lower emissions.

Battery Storage: BESS significantly reduces carbon emissions when paired with renewables, supporting near-zero-emission operations and aligning with sustainability objectives.

SMRs: SMRs provide carbon-neutral energy during operation, making them critical for long-term decarbonization efforts at permanent installations.

Microreactors: With minimal emissions and compatibility with renewable integrations, microreactors enhance sustainability for mobile and temporary operations.

Strategic Applications

Microgrids: Microgrids are ideal for critical infrastructure and contingency bases, providing resilient energy solutions in areas prone to grid disruptions. Their ability to integrate diverse energy sources ensures versatility in military applications.

Solar & Wind: Solar and wind energy are strategically deployed in installations with abundant sunlight or wind resources. They are particularly valuable in remote or austere locations where fuel logistics pose challenges.

Vehicle-to-Grid (V2G): V2G systems provide strategic advantages by enabling vehicles to serve dual purposes as transport and mobile power units, enhancing operational flexibility in remote and contested environments.

Battery Storage: Best suited for hybrid energy systems, batteries excel in backup power, silent operations, and renewable integration, especially for tactical units and covert missions.

SMRs: Essential for energy-intensive installations, SMRs ensure autonomy and long-term reliability, aligning with DoD's strategic goals for resilient infrastructure.

Microreactors: Microreactors' portability and rapid deployment capabilities make them indispensable for forward-deployed units, disaster relief, and scenarios requiring flexible energy solutions.

Operational Logistics:

Some of these technologies may feasibly be employed within the context of Expeditionary Advanced Base Operations (EABO). EABO are "a foundational naval concept to address challenges created by potential adversary advantages in geographic location, weapons system range, precision, and capacity. It also created opportunities by improving [the Marine Corps'] own ability to maneuver and exploit control over key maritime terrain, fully integrating Fleet Marine Force (FMF) and Navy capabilities to enable sea denial and sea control, and support sustainment of the fleet."[42] Thus, one of the primary missions of EABO is to "provide forward sustainment to support and enable the joint force," which in a future conflict may

[42] Department of the Navy Headquarters, United States Marine Corps, *Tentative Manual for Expeditionary Advanced Base Operations (2nd Edition)*, 1-1, May 9, 2023, https://www.marines.mil/Portals/1/Docs/230509-Tentative-Manual-For-Expeditionary-Advanced-Base-Operations-2nd-Edition.pdf?ver=05KvG8wWlhI7uE0amD5uYg%3d%3d.

involve the refueling of autonomous vehicles employed in the aforementioned Hellscape concept.[43]

First, the personnel requirements and deployment time of small modular reactors (SMR) make them unfeasible for EABO. The quickest turnaround for a given reactor would be several weeks, which would give potential adversaries enough time to acquire and destroy the asset. As such, they may be feasible within the context of more permanent operating bases, such as potential supply or logistical depots for the Army.

By contrast, the Tactical Energy Storage Unit (TESU) developed by Cummins and the High-Temperature Gas-Cooled Micro Modular Reactor (HI-MMR) developed by Holos may prove to be the most useful to expeditionary base operations conducted by the Navy and Marine Corps. First, the TESU, being trailer-mounted, deployable in under 10 minutes, and requiring minimal technical expertise to operate, has a small "footprint" and thus will be easily integrable into existing logistics systems and networks – for instance, it could be moved by amphibious craft for easy ship-to-shore transport. The TESU is mobile, persistent, and low-signature, all characteristic of advanced expeditionary base operations doctrine.[44] Second, although the HI-MMR has a larger footprint, it also has a much larger capacity of up to 10 mW, versus 60 kW for the former. This is to say nothing of the fact that the HI-MMR produces energy much more efficiently than the current diesel generator configuration.[45] Further, the HI-MMR is capable of being fitted into an ISO container, which in turn means that the HI-MMR system can be loaded onto C-130 platforms.[46] In turn, C-130s have proven themselves capable of rapid-deploying

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[43] Department of the Navy Headquarters, United States Marine Corps, *Tentative Manual*, 1-3.
[44] Department of the Navy Headquarters, United States Marine Corps, *Tentative Manual*, 1-4.
[45] Kenneth S Allen, Samuel K Hartford, and Gregory J Merkel, "Feasibility Study of a Micro Modular Reactor for Military Ground Applications," *Journal of Defense Management* 08, no. 01 (2018): 1, https://doi.org/10.4172/2167-0374.1000172.
[46] CDK Global, "C-130 Loading Kits," CDK Mobile Systems, https://www.cdkmobile.com/c130%20kit%20full.htm#:~:text=The%20CLT%20system%2C%20M1022%2DA1,tall)

assets like the High Mobility Artillery Rocket System (HIMARS) into contested environments. Moreover, the 72-hour timeframe on deploying HI-MMR systems would enable the high operational tempo required by EABO, and is consistent with the Marine Aviation mission set of "aviation ground support."[47] In sum, the logistical requirements of the TESU and HI-MMR are consistent with current Navy/Marine Corps capabilities and doctrine, and in turn these systems provide the sustainment necessary for EABO operations.

[47] Department of the Navy Headquarters, United States Marine Corps, *Tentative Manual*, 5-4.

Bibliography

Allen, K. S., S. K. Hartford, and G. J. Merkel. "Feasibility study of a micro modular reactor for military ground applications." *J. Def. Manag* 8, no. 172 (2018): 2167-0374.

Andres, Richard B., and Hanna L. Brett. "Small nuclear reactors for military installations: capabilities, costs, and technological implications." (2011).

Barry, Nicholas, and Surya Santoso. "Modernizing Tactical Military Microgrids to Keep Pace with the Electrification of Warfare." *Military Review*, December 2022. Accessed February 19, 2025. https://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/November-December-2022/Barry/.

Carbon Credits. "Why the U.S. Military Moves Toward Nuclear to Power Its Bases in 2030s." *Carbon Credits News,* July 15, 2024. https://carboncredits.com/why-the-u-s-military-moves-toward-nuclear-to-power-its-bases-in-2030s/.

CDK Global. "C-130 Loading Kits." CDK Mobile Systems. https://www.cdkmobile.com/c130%20kit%20full.htm#:~:text=The%20CLT%20system%2C%20M1022%2DA1,tall).

Center for Climate and Energy Solutions (blog). Accessed February 19, 2025. https://www.c2es.org/content/microgrids/#:~:text=Microgrids%20commonly%20range%20in%20size,otherwise%20receive%20from%20the%20macrogrid.

Cybersecurity and Infrastructure Security Agency. "Cybersecurity for Clean Energy Systems." *CISA Website,* 2024. https://www.cisa.gov.

"DC Microgrids Are Going Mainstream – Fast!" *Microgrid Knowledge* (blog), May 10, 2023. https://www.microgridknowledge.com/sponsored/article/33004797/alencon-systems-dc-microgrids-are-going-mainstream-fast.

Department of Defense. "Replicator." Defense Innovation Unit. https://www.diu.mil/replicator.

Department of the Navy Headquarters, United States Marine Corps. *Tentative Manual for Expeditionary Advanced Base Operations (2nd Edition)*. May 9, 2023. https://www.marines.mil/Portals/1/Docs/230509-Tentative-Manual-For-Expeditionary-Advanced-Base-Operations-2nd-Edition.pdf?ver=05KvG8wWlhI7uE0amD5uYg%3d%3d.

"DOD's Need for a Transportable Energy Solution: The Promise of Nuclear Power." *Joint Force Quarterly (JFQ)* 113, nos. 2nd Quarter (2024). Defense Logistics Agency.

Enercon Power. "The Role of Electric Drones in Military Applications." Enercon. Last modified June 12, 2024. https://www.enerconpower.com/post/the-role-of-electric-drones-in-military-applications#:~:text=In%20online%20with%20the%20development,recharge%20drones%20on%20the%20move.

Energy Blockchain Consortium. "Blockchain Applications in Energy Management." *Energy Blockchain Consortium Publications,* 2024. https://energyblockchainconsortium.org.

"Enhancing Operational Readiness: The Tactical Microgrid Standard and The Impact of Microgrids on Modern Military Bases." *PowerSecure* (blog), December 17, 2024. https://powersecure.com/blog/enhancing-operational-readiness-the-tactical-microgrid-standard-and-the-impact-of-microgrids-on-modern-military-bases.

Eversden, Andrew. "Army electric vehicle goals 'pretty darn achievable,' but challenges remain." *Breaking Defense*, March 2, 2022. Accessed February 19, 2025.

https://breakingdefense.com/2022/03/army-electric-vehicle-goals-pretty-darn-achievable-but-challenges-remain/.

Fagerberg, Jan. "Innovation policy: Rationales, lessons and challenges." *Journal of Economic Surveys* 31, no. 2 (2017): 497-512.

Filadelfo, Ronald. "The Feasibility of Small Modular Reactors for Military Installations." *Deni, New Realities: Energy Security in the 2010s and Implications for the US Military*: 343-356.

Hirsch, Adam, Yael Parag, and Josep Guerrero. "Microgrids: A review of technologies, key drivers, and outstanding issues." *Renewable and Sustainable Energy Reviews* 90 (July 2018): 402-11. Accessed February 19, 2025. https://doi.org/10.1016/j.rser.2018.03.040.

Hokenson, Alex. "Rescuing the nuclear renaissance: Why the military should adopt small modular reactors." *Geo. Wash. J. Energy & Envtl. L.* 7 (2016): 242.

Horowitz, Michael C., and Joshua A. Schwartz. "To Compete or Strategically Retreat? The Global Diffusion of Reconnaissance Strike." *Journal of Peace Research*, September 21, 2024. https://doi.org/10.1177/00223433241261566.

Ichord, Robert F., and Jennifer T. Gordon. "Innovation in Nuclear Energy Technologies: Implications for US National Defense." *Atlantic Council*, 2020. JSTOR.

Leemans, Ryan, and Vikram Mittal. "A Systems Approach for Analyzing Operational Energy Requirements for the Warfighter." In *2019 IEEE International Systems Conference (SysCon)*, pp. 1-7. IEEE, 2019.

Lindner, Donna. "Air Force Develops New, Deployable, Energy Systems." U.S. Department of Defense. Last modified April 6, 2025.

https://www.defense.gov/News/News-Stories/Article/Article/1143863/air-force-develops-new-deployable-energy-systems/.

Lucà Trombetta, Giovanni, Salvatore Gianluca Leonardi, Davide Aloisio, Laura Andaloro, and Francesco Sergi. "Lithium-ion batteries on board: A review on their integration for enabling the energy transition in shipping industry." *Energies* 17, no. 5 (2024): 1019.

Lucchese, Felipe C., Luciane N. Canha, Wagner S. Brignol, Camilo AS Rangel, Bruno K. Hammerschmitt, and Criciele C. Castro. "A review on energy storage systems and military applications." In *2020 55th International Universities Power Engineering Conference (UPEC)*, pp. 1-5. IEEE, 2020.

MacDonald, Alistair. "Why Lasers Could Be Kryptonite for Drones." *The Wall Street Journal* (New York City, NY), October 14, 2024. https://www.wsj.com/business/why-lasers-could-be-kryptonite-for-drones-88e4cd4e.

Maheras, Steven J., Shane A. Foss, Ryanne E. Reed, Caitlin A. Condon, and Tristan R. Hay. *Microreactor Transportation Emergency Planning Challenges*. No. PNNL-34816 Revision 1. Pacific Northwest National Laboratory (PNNL), Richland, WA (United States), 2024.

Mignacca, Benito, Ahmad Hasan Alawneh, and Giorgio Locatelli. "Transportation of small modular reactor modules: What do the experts say?." In *The Proceedings of the International Conference on Nuclear Engineering (ICONE) 2019.27*, p. 1235. The Japan Society of Mechanical Engineers, 2019.

National Institute of Standards and Technology (NIST). "National Initiative for Cybersecurity Education (NICE)." *NICE Program Overview,* 2024. https://www.nist.gov/itl/applied-cybersecurity/nice.

Nxumalo, Zakhele C., Paul Tarwireyi, and Matthew O. Adigun. "Lithium-based batteries in tactical military applications: A review." In *2015 International Conference on Computer, Communications, and Control Technology (I4CT)*, pp. 575-579. IEEE, 2015.

Pettyjohn, Stacie. *Evolution Not Revolution: Drone Warfare in Russia's 2022 Invasion of Ukraine*. Center for a New American Security, 2024. JSTOR.

"Rapid 150 kW." Heliox. Accessed February 19, 2025. https://www.heliox-energy.com/products/rapid-150kw-modular.

Renahan, Timothy. "Realizing Energy Independence on U.S. Military Bases." *Joint Force Quarterly (JFQ)* 103, nos. 4th Quarter (2021).

Roza, David. "Why the Military May Need Microgrids for Overseas Bases to Win a Near-Peer Fight." *Air & Space Forces Magazine* (blog), October 31, 2023. https://www.airandspaceforces.com/air-force-military-overseas-bases-microgrids-power/.

S Allen, Kenneth, Samuel K Hartford, and Gregory J Merkel. "Feasibility Study of a Micro Modular Reactor for Military Ground Applications." *Journal of Defense Management* 08, no. 01 (2018). https://doi.org/10.4172/2167-0374.1000172.

Sayler, Kelley. "A WORLD OF PROLIFERATED DRONES: A Technology Primer." *Center for a New American Security*, 2015. JSTOR.

Shively, Bob. "The U.S. Army Uses Microgrids to Provide Resiliency, Address Climate Change, and Control Costs." *Energy Currents* (blog). Accessed February 19, 2025. https://www.enerdynamics.com/Energy-Currents_Blog/The-US-Army-Uses-Microgrids-to-Provide-Resiliency-Address-Climate-Change-and-Control-Costs.aspx#:~:text=During%20emergency%20operations%2C%20the%20microgrid%20will%20supply%20the%20base's%20needs,generators%20available%20on%20the%20market.

Soderberg, Andrew. "Battery Technology and the Military EV Transition." *American Security Project* (blog), February 9, 2023. https://www.americansecurityproject.org/battery-technology-and-the-military-ev-transition/.

Tadjdeh, Yasmin. "Electric Vehicles for the Military Still a Pipedream." *National Defense*. Accessed February 19, 2025. https://www.nationaldefensemagazine.org/articles/2021/10/6/electric-vehicles-for-the-military-still-a-pipedream.

U.S. Department of Defense, Office of the Under Secretary of Defense (Comptroller). *National Defense Budget Estimates for FY 2025 (Green Book).* Washington, DC: Department of Defense, 2024. https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2025/fy25_Green_Book.pdf

"Unified Facilities Criteria (UFC) Resilient Installation Microgrid Design." N.d. PDF.

U.S. Department of Defense. *Military and Security Developments Involving the People's Republic of China*. December 18, 2024. https://media.defense.gov/2024/Dec/18/2003615520/-1/-1/0/MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA-2024.PDF.

van den Bergh, Jeroen CJM, Albert Faber, Annemarth M. Idenburg, and Frans H. Oosterhuis. "Survival of the greenest: evolutionary economics and policies for energy innovation." *Environmental sciences* 3, no. 1 (2006): 57-71.

"Vehicle-to-grid (V2G) technology: Key challenges and developments." *Virta* (blog), January 18, 2023. https://www.virta.global/blog/v2g-technology-key-challenges-and-developments.

Walton, Rod. "Assistant Army Secretary: Military Advancing in its Work Deploying Microgrids at Bases." *Microgrid Knowledge* (blog), October 9, 2023. https://www.microgridknowledge.com/military-microgrids/article/33012906/us-military-advancing-in-its-embrace-of-microgrids-at-bases?utm_source=chatgpt.com.