Enabling Island Defense Through Resilient Power

USC SHIELD 2025 Capstone Project

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Executive Summary

Over the past two decades, the United States' strategic focus on the Global War on Terrorism reduced attention to emerging threats in the Indo-Pacific, notably the accelerated military modernization of the People's Republic of China. This modernization significantly enhanced China's missile capabilities, exemplified by the rapid expansion of the People's Liberation Army Rocket Force (PLARF). The PLARF's deployment of advanced missile systems—including anti-ship ballistic missiles (DF-21D), intermediate-range ballistic missiles (DF-26), and hypersonic glide vehicles (DF-17)—directly challenges U.S. strategic power projection across the Indo-Pacific islands.

In response, the Pacific Deterrence Initiative (PDI) was established in March 2023. An excerpt from the 2024 PDI states, "China is a pacing challenge... To win in an Indo-Pacific theater contingency, it is imperative that the U.S. modernizes and strengthens aging capabilities... Forward-based and rotational Joint Forces armed with the right capabilities demonstrate resolve, assure allies and partners and provide flexible response options... DoD must posture the force to permit effective and timely employment to credibly deter and/or decisively engage in a future fight, if necessary" (DoD, 2023c, p. 6). A key component of the PDI is Integrated Air and Missile Defense (IAMD), involving both the Missile Defense Agency and the U.S. Army through systems such as Aegis, THAAD, Indirect Fire Protection Capability Increment 2, Patriot, Sentinel Radars, Lower Tier Air and Missile Defense Sensor, and Strategic Mid-Range Capability (DoD, 2023c).

These IAMD systems rely on power from diesel generators or shore power. Shore power is an alternative method for powering critical functions without running a vehicle's engine or generator. Reliance on the systems' organic generators creates massive fuel demands and significant logistical challenges in resupplying the Indo-Pacific. Resupply ships become high-value targets with no self-defense, forcing the operational force to allocate additional resources for protection. This dependency on fuel is unsustainable long-term, making shore power the preferred solution for extended operations.

However, many Pacific Islands lack the infrastructure and distribution system to provide a reliable, resilient power supply to support PDI IAMD systems. Thus, this research investigates sustainable off-grid power solutions essential for supporting IAMD across the Pacific.

The study evaluates emerging off-grid solutions, including hybrid renewable microgrids, mobile nuclear microreactors, and hydrogen fuel infrastructure. Hybrid microgrids offer decentralized, scalable energy with reduced fuel vulnerabilities but require advanced storage due to intermittent output. Project Pele's mobile nuclear microreactors deliver robust, continuous power, minimizing logistics burdens linked to diesel systems. Hydrogen fuel and production technologies offer clean, local alternatives that reduce reliance on vulnerable supply lines.

Key recommendations include immediate investment in hybrid microgrids, accelerated deployment of mobile reactors, and integration of hydrogen fuel systems. The report also emphasizes strategic partnerships with regional allies like Japan, Australia, and South Korea to develop secure, interoperable energy networks.

Implementing these steps through a phased, collaborative approach will strengthen the strategic posture and operational resilience of U.S. IAMD capabilities, effectively countering evolving threats in the Indo-Pacific.

Introduction

In the first two decades of the 21st century, the primary focus of the United States Department of Defense and related agencies was on the Global War on Terrorism (GWOT). Following the September 11, 2001, terrorist attacks, the U.S. concentrated significant resources on addressing threats from radical Islam and engaging in prolonged counterinsurgency operations in the Middle East. Consequently, the strategic attention of the U.S. was largely diverted from other regions, notably the Indo-Pacific. Starting with the 1996 Taiwan Strait Crisis and continuing throughout the GWOT era, the People's Republic of China (PRC) pursued rapid and substantial military modernization, particularly emphasizing offensive missile capabilities, to counterbalance the U.S. military's dominant power.

Amid this period, the People's Liberation Army Second Artillery Force grew substantially, transforming into the People's Liberation Army Rocket Force (PLARF). The PLARF experienced exponential expansion, adding approximately 23 new brigades, with at least ten established in the immediate three-year span following its 2016 rebranding (Xiu, 2022). Additionally, the PLARF has introduced advanced missile systems such as the DF-21D anti-ship ballistic missile, DF-26 dual nuclear/conventional Intermediate Range Ballistic Missile, and the DF-17 hypersonic glide vehicle (Xiu, 2022). Under the leadership of Xi Jinping, China's aggressive rhetoric towards reunifying Taiwan further exacerbates regional tensions, increasing the potential for military conflict. The PLARF represents a significant evolution of China's strategic military capabilities. Scholars argue that the modernization of PLARF capabilities directly threatens U.S. operational freedom within the First and Second Island Chains, fundamentally altering regional security dynamics (Xiu, 2022; RAND Corporation, 2022). The existing literature emphasizes an urgent need for the U.S. to counteract the PLARF's growing strategic advantages. Figure 1 illustrates China's modernization of missiles for the PLARF.

Figure 1Figure 1

Illustration of China's Ballistic and Cruise Missiles.

China has the most active and diverse missile development program in the world. China is modernizing its ICBMs, developing multiple independently targetable reentry vehicles and hypersonic boost-glide vehicles. China's navy is also deploying a new fleet of nuclear ballistic missile submarines. China's advances in ISR and maneuvering reentry vehicles have given it an emerging capability to attack large naval vessels with long-range ballistic missiles.

Note. Adapted from Missile Defense Project, "Missiles of China," *Missile Threat*, Center for Strategic and International Studies, 2021.

The United States retains its strategic ability to project military power throughout the Indo-Pacific region, supported by territories like Hawaii and Guam and regional allies and partners, including Japan, the Republic of Korea, Australia, and the Republic of the Philippines. However, the advanced missile capabilities of the PLARF present a significant challenge, compelling the U.S. and its allies to urgently enhance their missile defense posture. Figure 2 illustrates the vastness of the Indo-Pacific and the countries in the region.

Figure 2

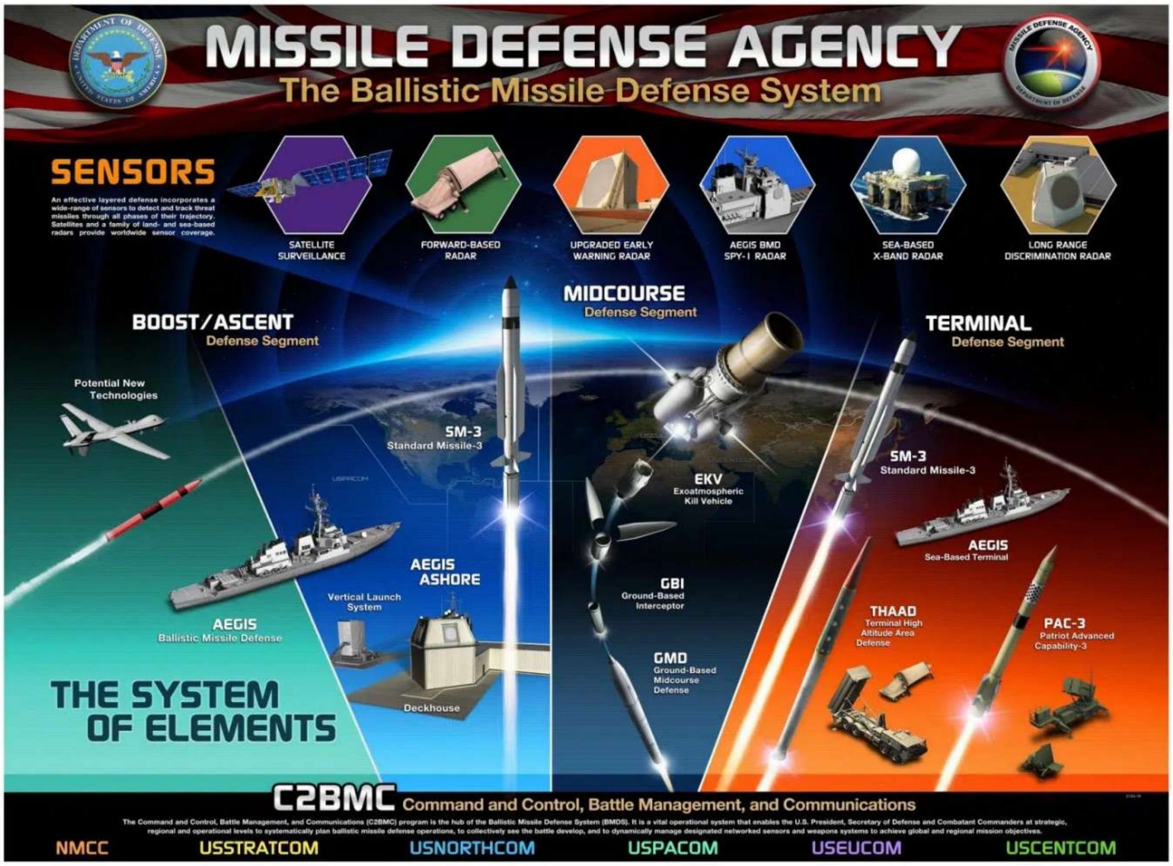
Illustration of the U.S. Indo-Pacific Command's Area of Operations.

Note. Reproduced from USINDOPACOM, *Area of Responsibility,* 2025 (https://www.pacom.mil/About-USINDOPACOM/USINDOPACOM-Area-of-Responsibility/)

In recent years, attempts to establish an effective joint integrated missile defense system for Guam and other Pacific installations have faced challenges with receiving the funds needed and the global demand for missile defense systems, specifically the demand in Central Command where friendly forces are under attack daily. Moreover, U.S. policy traditionally prioritized missile defense against threats from North Korea and Iran, rather than the more advanced missile capabilities of China and Russia. Recent shifts in U.S. policy, including the "Golden Dome" Executive Order signed by President Donald Trump in January 2025, underscore a renewed commitment to missile defense, resilience, and strategic partnerships. This executive order emphasizes maintaining next-generation missile defense capabilities, secure and resilient supply chains, and enhanced international collaboration (Trump, 2025). Figure 3 illustrates the current missile defense system.

Figure 3

Illustration of the Ballistic Missile Defense System



An effective layered defense incorporates a wide-range of sensors to detect and track threat missiles through all phases of their trajectory. Satellites and a family of land- and sea-based radars provide worldwide sensor coverage.

The Command and Control, Battle Management, and Communications (C2BMC) program is the hub of the Ballistic Missile Defense System (BMDS). It is a vital operational system that enables the U.S. President, Secretary of Defense and Combatant Commanders at strategic, regional and operational levels to systematically plan ballistic missile defense operations, to collectively see the battle develop, and to dynamically manage designated networked sensors and weapons systems to achieve global and regional mission objectives.

Note: Adapted from *Biden should guide missile defense his own way. Bulletin of the Atomic Scientists,* by Barzashka, I., 2021 (https://thebulletin.org/2021/09/biden-should-guide-missile-defense-his-own-way/)

A critical component of implementing this executive order and addressing the strategic challenge posed by the PRC is ensuring a continuous, resilient power supply for U.S. military installations and remote-fixed sites dispersed across Pacific Islands. Traditional power sources like diesel generators are vulnerable due to their dependence on extensive logistics lines, making them unreliable as a stand-alone source of power in austere or contested environments (Naval Postgraduate School, 2021; GAO, 2022). Therefore the integration of, innovative, off-grid power solutions, such as Project Pele's mobile nuclear microreactors, are essential to sustain military operations, enhance mission effectiveness, and support comprehensive integrated air and missile defense strategies across the Indo-Pacific region (SCO, 2023).

Problem Statement

The Pacific Defense Initiative (PDI) and the rapid growth of the PLARF's missile capabilities during the U.S. focus on the Global War on Terrorism have created an urgent demand for Integrated Air and Missile Defense (IAMD) capabilities to rapidly modernize. This modernization makes it critical to address the escalating threat to the United States and its allies' ability to project power across the islands within the Indo-Pacific, particularly within contested areas such as the First and Second Island Chains. The first comprises the Kuril Islands, the main Japanese archipelago, Okinawa, the northern part of the Philippine archipelagos, the Malay Peninsula, and Taiwan. The second chain consists of the islands of Japan stretching to Guam and the islands of Micronesia. The current reliance on diesel generators and intermittent renewable energy sources introduces significant operational risks and vulnerabilities, including a massive fuel requirement which creates a logistical nightmare when re-supplying these island chains. The re-supply ships become high value targets for adversaries with no organic self-defense, which creates another requirement for the operational force to dedicate assets to protect these re-supply ships. This logistical requirement is not sustainable long-term. The United States military requires a resilient, reliable, and expeditionary solution for island defense, ensuring continuous operational readiness even within the adversary's weapons engagement zone. Achieving this strategic goal hinges on securing a resilient and reliable power solution. This paper identifies deployable power options capable of supporting expeditionary IAMD operations and examines the associated logistical, security, safety, and policy challenges faced by the United States and its allies in implementing these solutions.

The following primary and secondary research questions are designed to systematically address these challenges and inform practical solutions:

Primary Research Question:

What are the most effective and sustainable off-grid power solutions to support U.S. IAMD operations across the Pacific Islands?

Secondary Research Questions:

1. How can these power solutions be efficiently deployed and maintained to ensure continuous operational readiness in austere environments?
2. What is the current U.S Air and Missile Defense architecture for island warfare and what are the energy requirements for this architecture?
3. What are the logistical and security challenges associated with transporting and setting up power infrastructure in remote Pacific locations?

4. How do different off-grid power solutions compare in terms of cost, scalability, and resilience in extreme weather conditions?
5. What role can renewable energy technologies play in reducing dependency on fuel resupply chains for military operations?
6. How can the U.S. enhance partnerships with Pacific allies to develop shared, secure, and resilient energy networks for regional defense?

Literature Review

U.S. Integrated Air and Missile Defense (IAMD) Strategy

The 2024 National Defense Authorization Act (NDAA) reinforces U.S. commitments to missile defense by allocating substantial funding, including $500 million towards collaborative missile defense programs such as the Iron Dome, David's Sling, and Arrow systems. This legislative development signals a significant policy shift towards enhancing missile defense capabilities, particularly against advanced threats from peer adversaries like China and Russia (Reuters, 2024).

U.S. IAMD strategies historically prioritized missile threats from North Korea and Iran, neglecting the more sophisticated capabilities of adversaries like China and Russia. The recent Missile Defense Review (DoD, 2023b) critiques past U.S. strategies for insufficient focus on peer-level adversaries, urging modernization and adaptation of U.S. missile defense systems to address China's advanced missile threats explicitly. Despite initiatives like the integrated missile defense system for Guam, existing literature highlights persistent gaps in capability deployment, technology integration, and strategic clarity (Government Accountability Office, 2022).

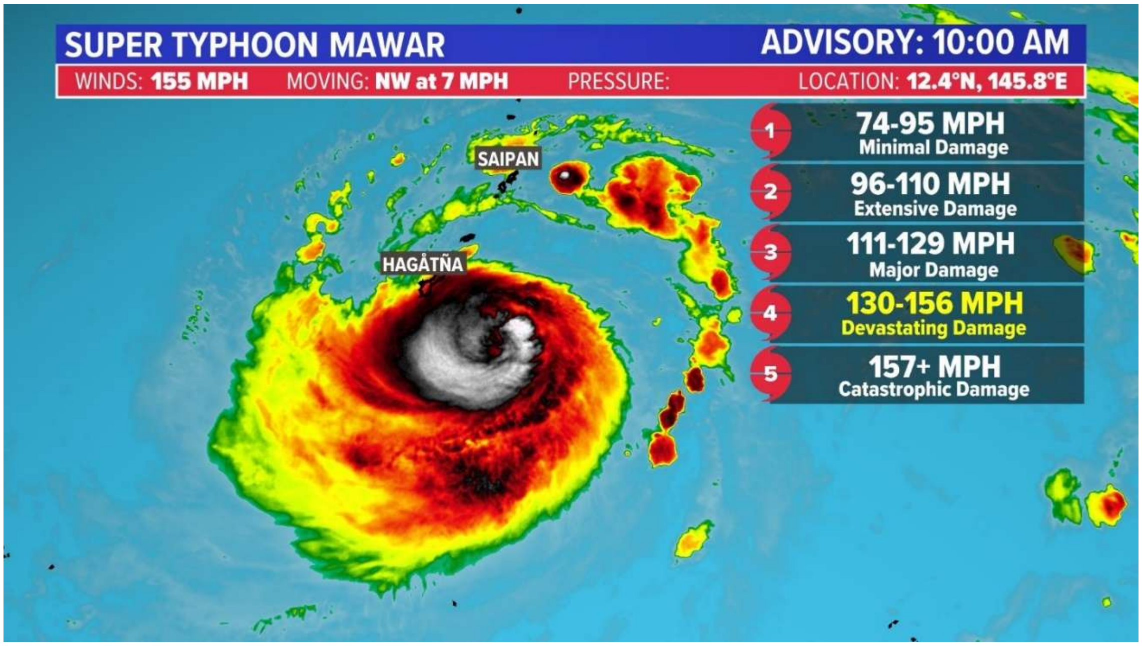
Power Challenges in Remote Military Operations

Research on power generation and sustainment in remote military environments consistently identifies logistical vulnerabilities associated with traditional diesel generators. The logistical burden of maintaining fuel supply lines, especially across contested waters and isolated islands, presents security vulnerabilities and limits operational flexibility (Naval Postgraduate School, 2021; GAO, 2022). Case studies from previous conflicts and operations underscore recurring challenges in maintaining consistent and reliable energy supplies, which critically impact mission readiness and resilience.

Historical Highlight of vulnerability of traditional power structure in South Pacific: Typhoon Mawar and Power Grid Fragility in Guam

Figure 4

Illustration of the destructive force of Super Typhoon Mawar in May 2023



Note. Derived from *KGW 8 News: Super Typhoon Mawar heading for Guam,* 2023 (https://www.kgw.com/article/news/nation-world/super-typhoon-mawar-hits-guam-cat-4-storm/507-c37a4a7d-c1c8-40de-adaf-fe94157f3fa2).

Typhoon Mawar, which struck Guam in May 2023, highlights the vulnerability of traditional power infrastructure. Over 90% of Guam experienced power, water, and communication disruptions (Taijeron, 2023). The military's dependency on Guam's centralized fossil fuel-based power grid was exposed as a critical strategic risk, underscoring the necessity for decentralized, robust, and resilient energy solutions capable of maintaining operational continuity in contested or austere environments. This spurred the beginning of Project Pele led by the Office of the Secretary of Defense – Strategic Capabilities Office or SCO (Waksman, 2024).

Emerging Power Technologies and Project Pele

Recent legislative support, including the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy (ADVANCE) Act enacted in July 2024, facilitates streamlined regulatory processes for advanced nuclear technologies, including small modular reactors (SMRs). This act is particularly relevant to military applications, as it can expedite the deployment of resilient energy solutions such as Project Pele's mobile nuclear reactors (ADVANCE Act, 2024).

A growing body of research explores innovative off-grid power solutions as practical alternatives for expeditionary military operations. Project Pele, spearheaded by the Strategic Capabilities Office, investigates mobile nuclear microreactors capable of offering high-energy outputs with reduced logistical demands and enhanced environmental sustainability (SCO, 2023). Comparative studies and initial feasibility reports suggest significant operational benefits over traditional diesel systems, although the literature also raises concerns about regulatory challenges, deployment logistics, and security risks inherent to nuclear energy deployment in forward environments (MITRE Corporation, 2022; Brookings Institution, 2023).

Renewable microgrid solutions combining solar, wind, and battery storage have received increased attention, demonstrating potential to substantially reduce fuel logistics demands. However, extensive studies also note variability and intermittent energy output as key limitations, emphasizing the necessity for robust integration with energy storage and distribution technologies (National Renewable Energy Laboratory, 2023).

Energy Storage and Distribution Systems

Advancements in energy storage technologies, such as lithium-ion and solid-state batteries, hydrogen fuel cells, and flywheel storage, are increasingly recognized as critical to operational resilience. Recent studies by the U.S. Department of Energy (DoE) emphasize the strategic importance of these storage solutions to mitigate intermittent renewable outputs and logistics disruptions (DoE, 2022). Emerging research also underscores the potential of advanced smart-grid technologies, including wireless energy transmission and adaptive energy management systems, in enhancing energy security and operational reliability for military applications (IEEE, 2023).

Identified Gaps and Research Opportunities

Current literature identifies clear knowledge gaps, particularly regarding integrated solutions that combine renewable energy technologies, nuclear microreactors, and advanced energy storage systems tailored specifically for military deployment in contested Pacific environments. While individual technologies have been extensively studied, comprehensive assessments addressing operational feasibility, resilience under hostile conditions, and logistical sustainability remain underexplored. This literature review therefore highlights a critical need for integrated, multidisciplinary research to develop practical, resilient power solutions for the U.S. IAMD strategy in the Indo-Pacific region.

Methodology

This research employs a comprehensive mixed-methods approach, integrating qualitative and quantitative methodologies to evaluate the feasibility and effectiveness of off-grid power solutions for supporting U.S. Integrated Air and Missile Defense (IAMD) operations in the Pacific region. The chosen approach facilitates an in-depth understanding of both technical and contextual dimensions relevant to the research objectives.

Research Design

A mixed-methods research design was selected to leverage the complementary strengths of quantitative data, providing measurable evaluations of technical specifications and performance metrics, and qualitative data, offering contextual insights into policy implications, operational feasibility, and strategic considerations. This design ensures rigorous analysis and facilitates triangulation, enhancing the validity and reliability of findings.

Data Collection

Data for this study were systematically collected from multiple credible sources to ensure comprehensive coverage and depth of analysis:

- **Military and Government Documents:** Official reports and strategic analyses published by the Department of Defense (DoD), Government Accountability Office (GAO), Strategic Capabilities Office (SCO), Congressional Research Service, as well as pertinent legislative documents, such as the National Defense Authorization Act (NDAA) and the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy (ADVANCE) Act.
- **Peer-Reviewed Academic Literature:** Scholarly articles sourced from reputable journals, addressing topics including missile defense strategies, military energy

resilience, renewable and nuclear energy technologies, and logistics in austere military environments.

- **Technical and Industry Reports:** Publications and technical evaluations from authoritative organizations such as the National Renewable Energy Laboratory (NREL), MITRE Corporation, Brookings Institution, and IEEE journals.
- **Interviews with Policy and Technology Experts:** Semi-structured interviews conducted with subject matter experts from government agencies, military personnel involved in strategic planning, and technology experts from industry and academia to provide practical insights, contextual understanding, and informed perspectives on operational and strategic challenges.

Analytical Methods

The study employs several analytical methods to rigorously assess collected data:

- **Comparative Analysis:** Systematic evaluation of different off-grid energy technologies, utilizing defined criteria such as logistical feasibility, reliability, scalability, cost-effectiveness, and operational resilience.
- **Case Study Analysis:** Detailed examination of historical and contemporary military deployments and operations, providing empirical evidence of successes, challenges, and practical implications of energy solutions in remote and contested environments.
- **Content and Policy Analysis:** Critical examination of strategic documents, policies, and legislation to understand the regulatory and political landscape influencing energy resilience initiatives and missile defense strategies.

- **Expert Opinion and Synthesis:** Integration of expert assessments and recommendations derived from literature and governmental publications to enhance depth and applicability of findings.

Evaluation Criteria

To ensure clarity and consistency in analysis, specific evaluation criteria were established:

- **Operational Feasibility:** Evaluates the ease of deployment, operational maintenance requirements, and suitability of technologies for austere and contested environments.
- **Energy Reliability and Resilience:** Measures the ability of power solutions to provide uninterrupted, sustainable energy under diverse operational scenarios, including hostile and adverse environmental conditions.
- **Cost and Logistical Efficiency:** Assesses lifecycle costs, initial investments, operational expenses, and logistical demands associated with transportation, setup, and sustained operation of technologies.
- **Security and Safety:** Analyzes vulnerabilities, security threats, regulatory compliance, environmental safety, and potential risks associated with the deployment of specific energy technologies, particularly focusing on nuclear power solutions.
- **Strategic Alignment and Policy Integration:** Reviews compatibility of proposed power solutions with U.S. strategic objectives, regional operational frameworks, and collaborative capabilities with international partners and allies.

By employing this rigorous methodological framework, the study provides robust, actionable insights and recommendations, aligning with graduate-level academic standards and supporting informed strategic decision-making for U.S. military operations in the Indo-Pacific region.

Analysis and Findings

IAMD Requirements in Indo-Pacific

The PDI and the PRC's Ballistic missile threats were used as the basis for IAMD island defense construct for energy requirements. Specifically referenced systems in the PDI for the IAMD was the Aegis, THAAD, IFPC Inc 2, Patriot, Sentinel Radars, LTAMDS, and Strategic mid-Range Capability (DoD, 2023a). For perspective the Patriot rocket launcher is powered by a 15KW generator, Sentinel utilizes a 10KW Generator, and THAAD utilizes a 10KW generator and averages 90 gallons of fuel consumption per hour. Therefore, when determining viable alternative energy options, the study focused on energy solutions that were portable and provided reliable and constant energy.

Hydrogen as a Fuel Source

Hydrogen is emerging as an effective alternative for military energy resilience and is currently under analysis for Patriot missile defense system generators. Hydrogen can be produced directly on-site, significantly reducing the logistical burden of fuel transportation. Japan and Australia have also already created a venture for creation and shipment of hydrogen via the first liquid hydrogen carrier (HESC, 2025).

The generated hydrogen can be utilized to power weapon systems, supply energy grids, or fuel hydrogen production facilities directly as shown in Figure 4.

Figure 5

Picture of the hydrogen fueled nanogrid demonstration at White Sands Missile Range .

Note. Adapted from *Engineer Research and Development Center Celebrates U.S. Army's First Hydrogen-Powered Nanogrid,* by Doosan Fuel Cell Works, 2025, (https://fuelcellsworks.com/2025 /01/09/energy-innovation/engineer-research-and-development-center-celebrates-us-army-s-first-hydrogen-powered-nanogrid).

Initiatives such as Korea's Doosan Fuel Cell's advancements demonstrate the viability of hydrogen fuel cells, which offer efficient, clean power generation with reduced environmental impacts. The Doosan Fuel Cell shown in figure 5 has the capability of producing 460kw.

Figure 6

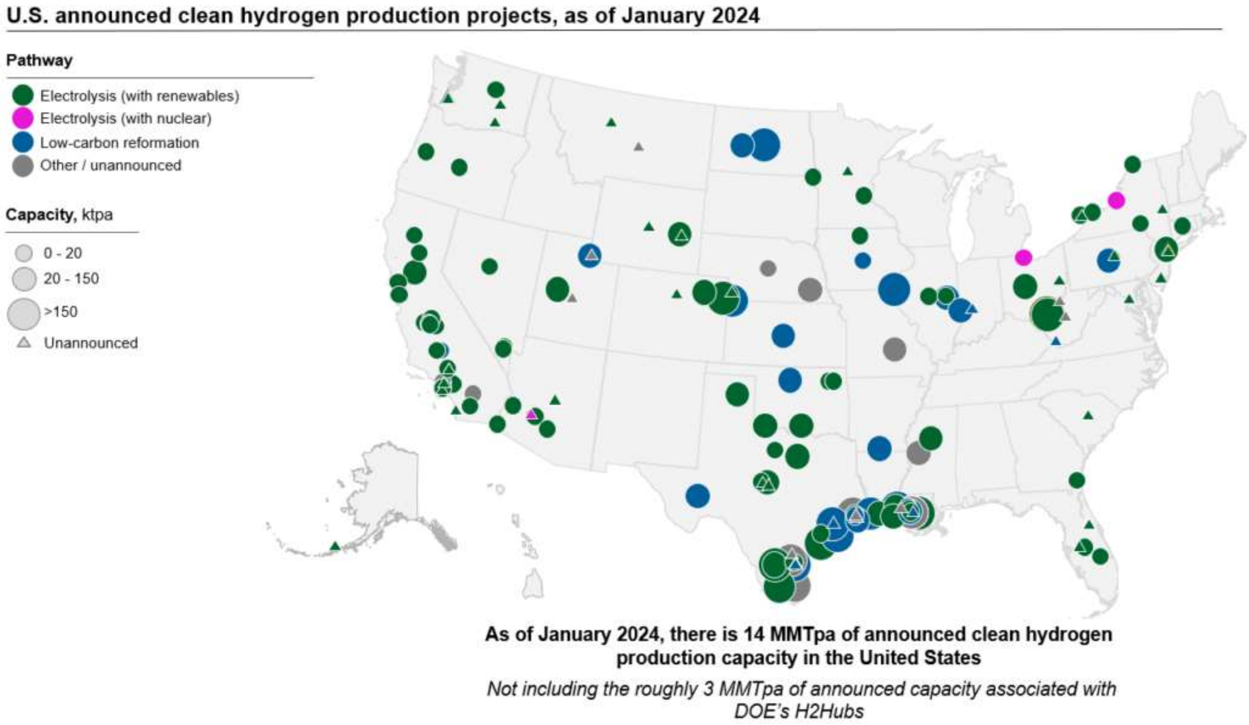
Doosan Fuel Cell.

Note. Adapted from *Doosan fuel cell power generation systems overview,* by Doosan Fuel Cell*,* 2024 (https://www.doosanfuelcell.com/en/products/power-generation).

The United States has announced clean hydrogen production projects showing the increase in investment and production as depicted below throughout the country. This increase and be leveraged to support military advancement or joint development of hydrogen production for military use.

Figure 7

Illustration of the U.S. Department of Energy's clean hydrogen projects as of January 2024



Note. Adapted from *U.S. Department of Energy's clean hydrogen projects as of January 2024,* by Department of Energy, 2025 (https://liftoff.energy.gov/clean-hydrogen/).

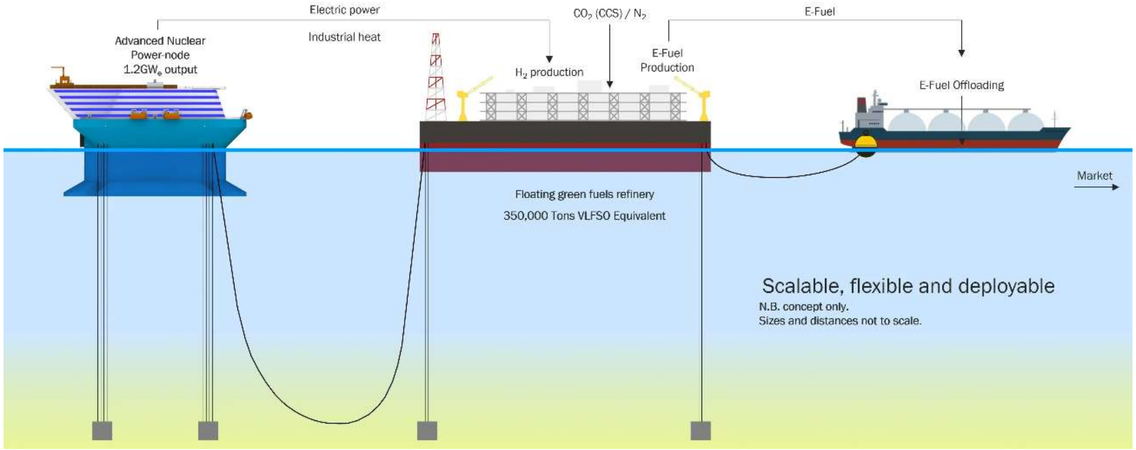
Hydrogen electrolysis from clean energy, such as nuclear, have the highest potential for long-term low-cost hydrogen supply.

Floating Nuclear Power Plants as a Power Source

Another possible solution for reliable and resilient power for Island Defense is floating nuclear power plants, like the one in development by CORE POWER in figure 8 (CORE POWER, 2025).

Figure 8

Illustration of floating nuclear power plants.



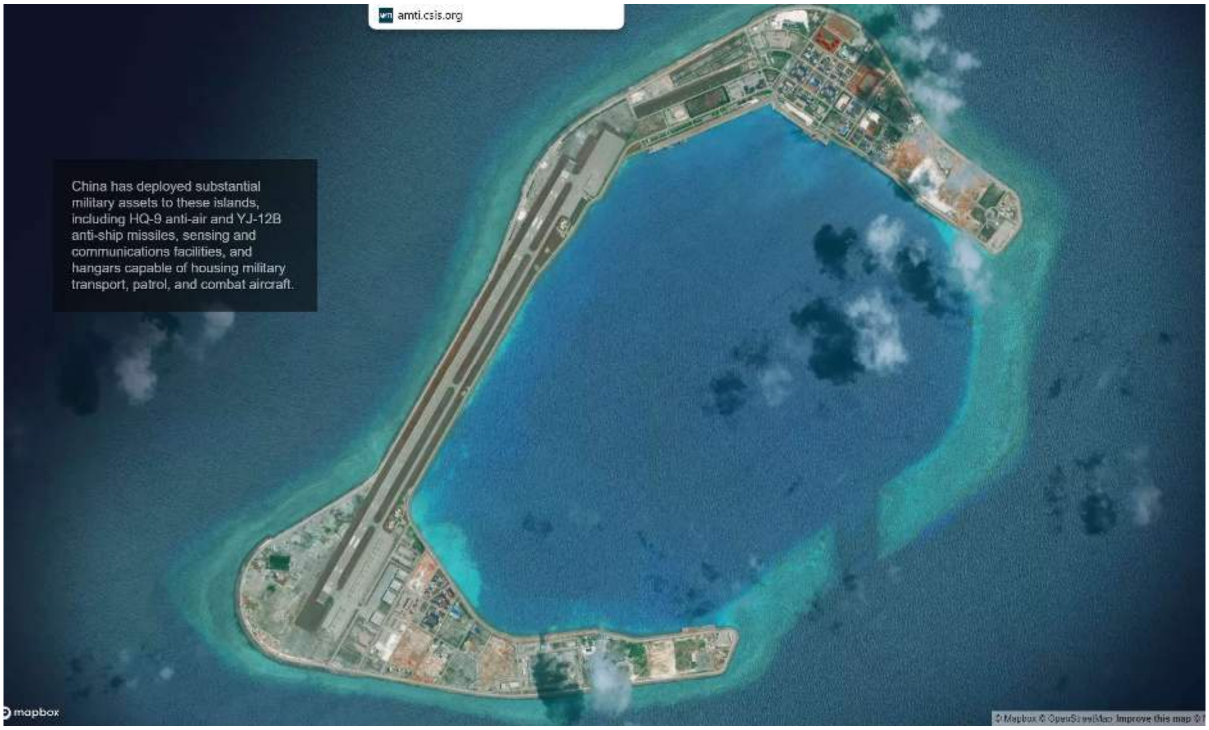
Note. Adapted from *Floating Electric Power*, by CORE POWER, 2025 (https://www.corepower.energy/maritime-applications/fnpp DoD).

Floating nuclear power plants have been in used for years, specifically by Russia (World Nuclear News, 2025). CORE POWER is pursing microreactor or larger size reactor models that can be tailor to power needs. These floating power plants would reduce initial costs to produce due to no site preparation or civil construction needs. They could reduce policy concerns that arise from land-based nuclear power plants and land-based environmental concerns. These plants would also be transportable to operational sites with rapid deployment to meet urgent needs. The offshore site shields the power plant from earthquakes and it could be relocated temporarily for typhoons. These plants would also have an unlimited source of water for cooling purposes.

In the past 20 years, China has built numerous artificial islands in the South China Sea and deceived the international community by arming these islands as unsinkable military bases like the overhead photo of Subi Reef in figure 9.

Figure 9

Imagery of one of China's man-made islands utilized for military activities



Note. Adapted from *By Air, Land, and Sea: China's Maritime Power Projection Network,* by CSIS, 2012 (https://amti.csis.org/power-projection-network/)

To power all these distributed outposts across the South China Sea, China is also looking at the use of floating nuclear power plants as a solution (Xue, 2024). This highlights the lack of power infrastructure in the region and that our adversaries are looking into alternative portable reliable energy sources.

Wave Energy Generators as a Power Source

With over 70% of the Earth's surface covered by the oceans, waves are a seemingly unlimited source of free and clean energy. Partially funded by the US Department of Energy (DoE), Ocean Energy USA has already deployed the world's first electrical grid scale wave energy device off Oahu, Hawaii as shown in figure 10 (Ocean Energy USA, 2025). Wave energy generators, though promising due to predictable oceanic energy sources, remain constrained by high initial costs, technological maturity issues, and vulnerability to harsh marine environments, limiting immediate deployment.

Figure 10

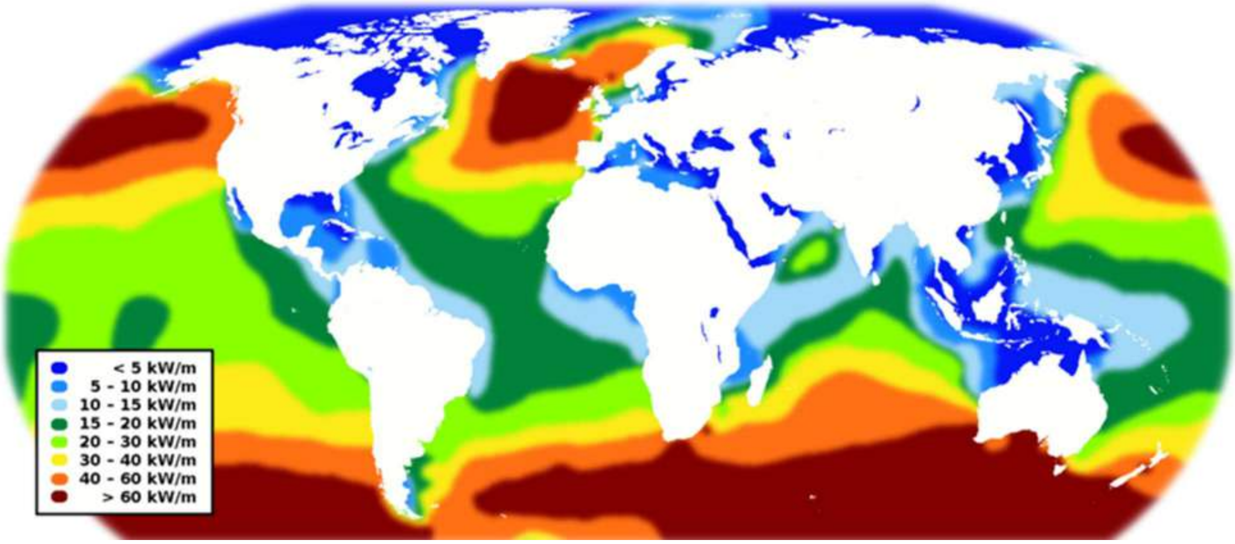
Picture of Ocean Energy USA's grid scale wave energy device off of Oahu, Hawaii

Note. Copied from *OE35,* by Ocean Energy USA, 2025 (https://oceanenergy.ie/oe35/).

These systems could be deployed in numerous locations throughout the Pacific to provide electrical energy to forces operating on remote Islands. Figure 11 below demonstrates that waves are a reliable energy source in the Pacific.

Figure 11

Illustration of where waves could provide a reliable energy source across the globe.



Note. Adapted from *Triton Wave Energy Converter,* by Oscilla Power, 2025 (https://www.oscillapower.com/technology).

The Triton wave energy converter from Oscilla Power in figure 12 and 13 are an additional option that already exists for wave power generation:

Figure 12

Picture of Oscilla Power wave generator

Note. Adapted from *Triton Wave Energy Converter,* by Oscilla Power, 2025 (https://www.oscillapower.com/technology)

Figure 13

Illustration of towing and emplacing Oscilla Power wave generator

Note. Adapted from *Triton Wave Energy Converter,* by Oscilla Power, 2025 (https://www.oscillapower.com/technology)

This energy wave converter system is high efficiency energy capture and conversion, is low cost to tow and drop into position, and is highly survivable and reliable (Oscilla Power, 2025). These devices could be quickly deployed throughout the Pacific to provide or supplement power grids and equipment on remote islands.

Operational Feasibility Analysis

Mobile nuclear microreactors, specifically Project Pele, offer significant operational advantages, including high energy output, reduced logistical burdens, and consistent performance independent of weather. Project Pele is being developed by the Strategic Capabilities Office partnered with BWXT Advanced Technologies, Virginia. Project Pele is projected to finish final assembly in February 2026. The goal of Project Pele is to produce 1-5 Megawatt Electric (MWe) for more than three years without refueling (Bhardwaj, 2024). One MWe is one million watts of electricity and refers to the electricity output capability of the plant (Energy Education Encyclopedia Team, n.d.). Project Pele is building the system in three 20ft Conex boxes as shown in figure 15 that are based off the size of the Army's pre-existing diesel generators. The three boxes, a reactor box, a power conversion box, and a command and control

(C2) box, are transportable via C-17 aircraft, making them quickly deployable to remote location. Current Project Pele data states the reactor can be operated by six personnel and it is a closed loop gas system that does not need water to flow through the reactor. Project Pele uses advanced technologies such as inherently safe, encapsulated Tri-structural isotropic particle (TRISO) fuel, enabling a highly autonomous and secure power source deployable by minimal personnel that can withstand extreme temperatures and a kinetic attack (Waksman, 2021). One Project Pele could provide resilient, carbon-free energy source capable of delivering reliable 24/7 power to mission-critical DoD operations in remote and austere environments (DoD, 2024). This would drastically reduce the fuel requirements and logistical vulnerabilities presented in the current PDI landscape. Although the benefits of Project Pele are clear, the product is faced with deployment challenges including complex regulatory processes, security considerations, and public acceptance issues. These issues are being resolved by the Strategic Capabilities Office but will have to be resolved prior to fielding a material solution to U.S Forces and deploying throughout the Indo-Pacific.

Figure 14

Illustration of the Project Pele being transported via ground transportation

Note. Adapted from *Project Pele, U.S. DoD to Build Mobile Nuclear Micro-Reactor for Battle Field Power Supply,* by A-1 channel, 2023, (https://www.youtube.com/watch?v=wQGjjD_1kaE)

Hybrid renewable microgrids, which integrate various renewable energy sources such as solar and wind with advanced energy storage technologies like lithium-ion batteries, have emerged as highly promising solutions for military energy resilience. Solar photovoltaic (PV) systems provide significant advantages due to their modular design, ease of deployment, and low maintenance requirements, making them particularly suitable for remote military installations (National Renewable Energy Laboratory, 2023). The scalability of solar PV systems allows rapid expansion or downsizing, aligning closely with changing operational demands and strategic priorities (MITRE Corporation, 2022).

Wind energy, another critical component of hybrid renewable microgrids, complements solar energy by generating power during periods when solar output is typically lower, such as nighttime or cloudy conditions. Studies conducted by the National Renewable Energy Laboratory indicate that integrating wind turbines into microgrids significantly reduces dependence on fossil fuels and enhances overall energy security, especially on islands and coastal locations with consistent wind resources (National Renewable Energy Laboratory, 2023). Moreover, military installations utilizing hybrid solar-wind systems have reported improved energy independence and operational flexibility, substantially reducing their vulnerability to disruptions in fuel supply chains (Naval Postgraduate School, 2021).

The effectiveness of renewable energy solutions relies heavily on advanced energy storage technologies to manage intermittent power production. Lithium-ion batteries, the most commonly deployed energy storage solution, have proven to be highly efficient and reliable in both civilian and military applications due to their high energy density, scalability, and decreasing costs (U.S. Department of Energy, 2022). Recent advances in lithium-ion battery technology have further enhanced their suitability for military operations, providing improved performance under extreme environmental conditions, extended lifespan, and increased energy storage capacities (IEEE, 2023).

Experimental military contexts further validate the operational feasibility of hybrid renewable microgrids. Demonstrations conducted by the U.S. Department of Defense at forward operating bases and remote installations show that microgrid systems combining solar, wind, and battery storage can significantly enhance operational resilience by reducing reliance on vulnerable supply chains and providing continuous, reliable power (Strategic Capabilities Office, 2023). These successful military experiments reinforce the adaptability and practicality of renewable microgrids as a critical component of future military energy strategies in contested environments.

Comparative Analysis of Solutions

Expert interviews reinforce that “the military’s overreliance on diesel generators significantly hampers operational flexibility,” and that “hybrid renewable and nuclear technologies offer superior resilience and reduced vulnerability in contested environments” (Marks, 2025).

Strategic Implications and Policy Alignment

Findings align with strategic priorities articulated in the 2024 NDAA and the bipartisan Advanced Nuclear for Clean Energy (ADVANCE) Act of 2024, emphasizing the need for secure, resilient, and expeditionary energy solutions. Efforts such as the Project Pele's nuclear microreactors, hybrid renewable microgrids, and hydrogen fuel cells directly support these strategic goals. However, amendments to the Energy Policy Act (EPAct) of 2005 would be required in the U.S. and international regulatory frameworks both pose potential barriers to deploying nuclear and hydrogen-based technologies, requiring proactive policy engagement and diplomacy with regional partners and allies (EPAct, 2005). Specifically, international regulations on nuclear non-proliferation, safety protocols, and environmental protection standards create challenges for widespread deployment of nuclear solutions. Similarly, hydrogen fuel technology, though strategically advantageous, necessitates careful management of storage, transportation, and international regulatory compliance to mitigate environmental and safety risks effectively. One policy expert noted, “Hydrogen’s logistical advantages and minimal environmental risk profile make it an attractive solution, but significant infrastructure development is still required for effective deployment” (Marks, 2025). Expert interviews underscore sustained policy support, coordinated investment, and international cooperation as critical for successfully integrating advanced energy solutions into broader military and defense frameworks within the Indo-Pacific region.

Summary of proposed energy solutions

Table 1 shows a comparison of proposed energy solutions ranking each evaluation criteria by low, moderate or high in their respective category. The table ranks evaluation criteria from most important to least important from left to right. Most important being operational feasibility and least important being initial & lifecycle costs. Hybrid renewable microgrids combined with advanced energy storage, mobile nuclear microreactors like Project Pele, and hydrogen production and fuel cell systems emerge as the most strategically viable solutions for meeting the resilient power needs of U.S. Integrated Air and Missile Defense operations across the Pacific theater.

Table 1

Proposed Energy Solutions to Power Island Defense Systems

Solution Type	Operational Feasibility	Reliability & Resilience	Logistical Sustainability	Security & Safety Risks	Initial & Lifecycle Costs	Average Power Generation*
Diesel Generators	High	Low (vulnerable to disruption)	Low (fuel logistics dependency)	High (fuel logistics risks)	Moderate (high fuel costs)	1-3 MW
Hybrid Renewable Microgrids	High	Moderate (storage dependent)	High (limited logistics)	Low	Moderate-High	500 kW-2MW
Mobile Nuclear Microreactors	Moderate-High	High (independent power)	High (minimal logistics)	Moderate-High	High (initial), Low (lifecycle)	1-10MW
Wave Energy Generators	Moderate-Low	Moderate-High	High	Moderate	High	250 kW-1MW
Hydrogen Fuel Cells	High	Moderate-High (storage dependent)	High (on-site production)	Moderate-Low	Moderate-High	100kW-1MW

Comparison of proposed energy solutions

**Average Power generation for each source of energy was derived from numerous sources. Diesel generator power ranges from 1 Megawatt to 3 Megawatts (U.S. Army Corps of Engineers, Technical Manual TM 5-6115). Hybrid renewable Microgrids range from 500 kilowatts to 2 Megawatts (NREL, 2023). Mobile nuclear reactors range from 1 to 10 Mega Watts (SCO, Project Pele, 2023). Wave energy generators produce 250 kilowatts to 1 Megawatt of power (Ocean Energy USA, Oscilla Power, 2025). Hydrogen fuel cells produce 100 kilowatts to 1 megawatt of energy (Doosan Fuel Cell, 2024).*

Note. Created by author. See "*" above for reference details.

Recommendations

Based on the analysis and findings, the following recommendations are proposed to effectively address power resiliency and reliability for U.S. Integrated Air and Missile Defense (IAMD) operations in the Indo-Pacific region:

1. **Accelerate Deployment of Hybrid Renewable Microgrids**
    - Prioritize investment in hybrid renewable microgrids integrating solar, wind, and advanced energy storage systems to reduce logistical vulnerabilities.

  - Collaborate with industry leaders and national laboratories to optimize the scalability and adaptability of these systems for military operations.

2. **Strategically Expand Project Pele (Mobile Nuclear Microreactors)**
   - Expedite regulatory approvals and deployment processes through proactive engagement with international regulatory bodies and allies.
   - Implement robust security and operational protocols addressing public safety, environmental protection, and nuclear non-proliferation concerns.
   - Leverage existing partnerships (e.g., Idaho National Laboratory) for accelerated development, testing, and demonstration of microreactor capabilities.
3. **Integrate Hydrogen Fuel Cells into Military Energy Infrastructure**
   - Initiate pilot programs utilizing hydrogen fuel cells for critical systems such as missile defense generators and distributed military installations.
   - Invest in on-site hydrogen production capabilities to minimize reliance on extended supply chains, collaborating with allies such as Japan and Australia already pioneering hydrogen logistics.
4. **Enhance International Policy Cooperation and Regulatory Alignment**
   - Proactively engage regional allies, such as Japan, Australia, and South Korea, to streamline regulatory frameworks and harmonize standards for advanced energy deployments.
   - Advocate for collaborative international forums to address environmental, safety, and proliferation concerns associated with nuclear and hydrogen energy solutions.

5. **Strengthen Infrastructure and Operational Resilience**
    - Prioritize investments in resilient, decentralized power infrastructures, particularly on strategically significant islands like Guam, to withstand natural disasters and conflict scenarios.
    - Develop rapid-response energy deployment teams specialized in establishing and maintaining energy infrastructure under austere and contested conditions.

These recommendations provide a structured approach for enhancing the resilience, reliability, and strategic alignment of power solutions critical for successful U.S. IAMD operations throughout the Indo-Pacific theater.

Implementation Plan

To effectively operationalize the recommendations outlined for enhancing power resiliency in support of U.S. Integrated Air and Missile Defense across the Pacific theater, the following phased implementation plan is proposed:

In the short term, approximately one to two years, the initial focus will be on launching hybrid renewable microgrid pilot projects. Strategic locations such as Guam, Hawaii, and various forward operating bases that are key nodes should be selected for these deployments. Collaboration with national laboratories, notably the National Renewable Energy Laboratory, will be essential for conducting comprehensive technical assessments and feasibility studies. Initial funding will likely be secured through existing Department of Defense energy resilience budgets and targeted appropriations. Concurrently, early deployment of mobile nuclear microreactors should be pursued. This includes completing regulatory approval processes, updating the U.S. Energy Policy Act to include nuclear and hydrogen power, coordinating with relevant domestic and international oversight agencies, deploying initial reactors at selected strategic locations, and providing extensive training for military personnel on operational and safety protocols. Additionally, pilot programs for hydrogen fuel production and fuel cell systems will need to be initiated, leveraging partnerships with experienced regional allies such as Japan and Australia.

In the medium term, approximately three to five years, the emphasis will shift toward broader deployment and infrastructure and distribution development. Renewable microgrid systems proven successful in initial pilots will be scaled and deployed to additional strategic island locations. Advanced energy storage solutions will be integrated to effectively manage power intermittency issues. Expanded deployment of small nuclear reactors will take place at additional key installations, supported by continuous refinement of regulatory and operational frameworks through ongoing dialogue with international oversight bodies. Simultaneously, advanced hydrogen infrastructure development will need to scale up, including widespread implementation of on-site hydrogen production and fuel cell facilities, increasingly integrating hydrogen solutions into the broader energy strategy.

Long-term strategic goals, approximately five to ten plus years, include establishing a fully integrated, redundant, and resilient energy network that combines renewable microgrids, nuclear microreactors, and hydrogen infrastructure across the entire Indo-Pacific region. This network will undergo continual modernization with emerging technologies to maintain strategic and technological advantages. The United States will actively position itself as a global leader advocating for safe, secure, and environmentally responsible deployment of advanced energy technologies in military contexts. Strengthening strategic energy alliances will be prioritized, formalizing partnerships and regulatory frameworks with key regional allies, including Japan, Australia, and South Korea, to enhance regional stability and interoperability.

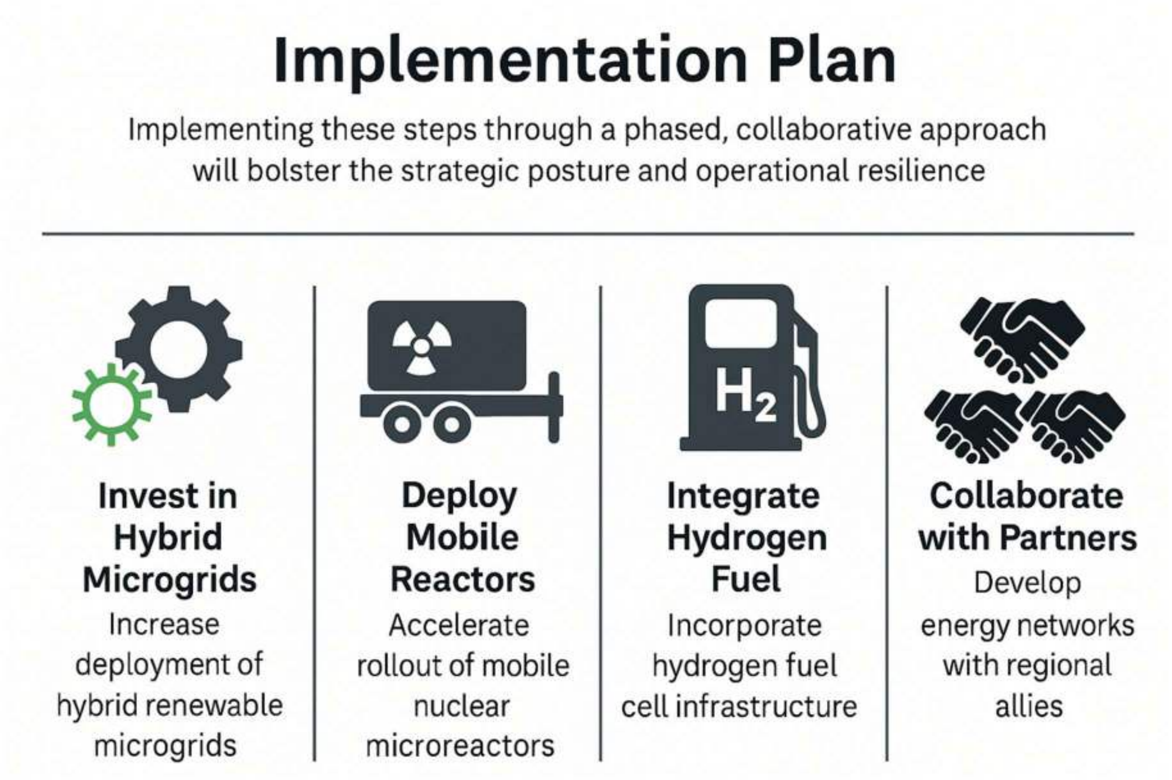
Key stakeholders critical to this implementation include the Department of Defense, will likely serve as the primary, initial funding entity for pilot projects; Congress, who will need to update energy policy and environmental policy; Industry, who will continue healthy competition to create safe energy technology; Energy Advocates, who will be both for and against new energy solutions; National laboratories, such as NREL and Idaho National Laboratory, providing essential technical expertise; and Regional allies assisting in coordination and infrastructure development.

Resource allocation will initially come from dedicated DoD energy resilience budgets and infrastructure appropriations, complemented by additional targeted Congressional appropriations for nuclear and hydrogen infrastructure. International cost-sharing arrangements will be pursued with regional allies to facilitate joint infrastructure projects. To ensure continuous progress and adaptability, evaluation and feedback mechanisms will be established. Regular stakeholder reviews will occur to assess technical performance, regulatory compliance, and operational readiness. Continuous feedback from operational commanders and allied partners will inform and refine implementation strategies. Annual strategic assessments will be conducted to ensure alignment with evolving military requirements, environmental standards, and geopolitical dynamics.

This detailed phased approach provides a realistic, structured, and actionable pathway to achieving strategically aligned, resilient, and reliable energy infrastructure critical to the operational success of U.S. IAMD forces in the Indo-Pacific. Figure 16 summarizes the major elements of this implementation plan.

Figure 15

Implementation Plan Summary



Note. Created by Author.

Conclusion

This research highlights the critical need for resilient and reliable energy infrastructure to effectively support U.S. Integrated Air and Missile Defense operations across the Indo-Pacific Theater. Current energy strategies are heavily dependent on fossil fuels, particularly diesel generators, expose significant logistical vulnerabilities and operational limitations against pacing threats that the PLARF possesses. This vulnerability underscores the necessity for the United States to rapidly transition toward innovative and resilient energy solutions.

The analysis conducted identified three promising technologies: hybrid renewable microgrids, mobile nuclear microreactors, and hydrogen fuel infrastructure. Hybrid renewable microgrids offer decentralized and scalable energy production, reducing dependency on vulnerable fuel supply chains. Mobile nuclear microreactors, particularly those developed under Project Pele, provide sustained high-output power critical for forward and strategically significant locations, substantially reducing logistical burdens. Hydrogen fuel infrastructure, including fuel cells and on-site hydrogen production, enhances operational flexibility and environmental safety while offering strategic logistical advantages.

Implementing these advanced energy solutions aligns directly with strategic military objectives by enhancing operational resilience, reducing vulnerabilities in contested environments, and improving overall sustainability and interoperability with regional allies. To realize these strategic benefits, the U.S. must proactively address international regulatory frameworks, foster robust partnerships with regional allies, and commit to ongoing technological and policy advancements.

Ultimately, by updating policy and successfully integrating these recommended technologies, the United States will strengthen its strategic posture, improve operational flexibility and resilience, and ensure effective deterrence and defense capabilities in the rapidly evolving geopolitical landscape of the Indo-Pacific.

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