Operational Energy Architectures Report

Pursuant to House Report 117-118, accompanying H.R. 4350, the National Defense Authorization Act (NDAA) for Fiscal Year 2022

Assistant Secretary of Defense
for Energy, Installations, and Environment

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Introduction

The Department of Defense (DoD) report on Operational Energy Architectures satisfies the reporting request in House Report 117-118, accompanying H.R. 4350, the National Defense Authorization Act (NDAA) for Fiscal Year 2022. House Report 117-118, page 87, requests that the Assistant Secretary of Defense for Energy, Installations, and Environment, in coordination with the Director of Logistics for the Joint Staff, the Assistant Service Secretaries of the military departments for Energy, Installations, and Environment, the Commander of U.S. Indo-Pacific Command, and the Director of the Defense Logistics Agency, submit a report to the House Committee on Armed Services that identifies and evaluates viable operational energy architectures.

Based on the request, the report includes the following: (1) an assessment of alternate-fuel-based commercial platforms and products, and the level of suitability, effort, and risk associated with adapting them for Department of Defense use; (2) a general discussion about potential performance benefits and corresponding operational benefits of platforms powered by alternate fuels, with a specific focus on the feasibility, benefits, and risks of using hydrogen fuels and cached hydrogen fuel feedstock for operational energy in expeditionary advanced base operations; (3) a discussion of current and future production capacity by U.S. allies and partners for fuel alternatives that could address demand in a contested environment, with a specific focus on the commercial availability of hydrogen and hydrogen fuel feedstocks within the U.S. Indo-Pacific Command area of responsibility; (4) a review of transportation safety and storage capacity for fuel alternatives, with a focus on the feasibility, benefits, and risks of transporting hydrogen gas in bulk as well as storing hydrogen fuel feedstocks; and (5) a list of recommendations for Department of Defense research and development investments to address the demand side of the contested logistics environment.

Assessment of Alternate-Fuel-Based Commercial Platforms and Products

For the purpose of this assessment, the Department considered the following types of alternatives to petroleum: electrification, hydrogen, and sustainable aviation fuels.

Electrification

Electrification technologies encompass land, sea (surface and subsurface), air and foot soldier platforms and offer substantial reductions in operational energy demand. The Department’s focus thus far has been on development programs focusing on applying anti-idle technologies and sequential hybridization to land platforms to increase fuel economy significantly and dramatically improve combat effectiveness. For sea platforms, development efforts are centered on electrification and hybridization of surface and subsurface platforms to improve fuel economy and provide additional electrical power to improved sensors and directed energy weapons. For air platforms, the Department is pursuing electrification and high-density power delivery technologies focusing on dramatic improvements to aircraft engines and electrification of unmanned aerial vehicles (UAVs).

Electrification Benefits, Risks, and Production Capacity by U.S Allies and Partners	
Performance Benefits and Reduction in Operational Energy Demand	• The use of anti-idle technologies with highly electrified components can yield a 25 percent fuel use reduction, 2X increase in silent watch capability and 3X-20X increase in exportable power for tactical vehicles. • For adaptive aircraft engines, benefits include 30 percent more range, 18 percent greater acceleration, increased cooling capability for onboard electronics, and more electricity to power emitting systems and directed-energy weapons. These capabilities will help offset the "tyranny of distance" in the Indo-Pacific Theater.
Feasibility and Technology Availability	• Anti-idle technologies and hydridization are well known technologies currently in use in ground vehicles. The Army and USMC have experimented extensively with anti-idle technologies and the Army plans to field hybrid tactical vehicles by 2035. The Navy has fielded hybrid and advanced propulsion systems on eight classes of combat logistics ships and four classes of combatants with two additional classes planned or under development. • Long-term challenges include sufficiently high-density batteries to fully electrify combat vehicles (tanks, infantry fighting vehicles), as well as timely battery charging or energy transfer for fully electric vehicles. • The performance requirements and difficulty of charging air and sea platforms makes these platforms the most difficult to electrify. • Over the near-term, unmanned systems are emerging as frequent applications for fully electrified propulsion.
Transportation Safety, Storage, and Supply Chain Risks	• Hybridized systems will reduce supply chain risks by reducing the volumes of liquid fuels required to be stored and distributed around the battlefield. • The supply chain risks of fully electric systems are not fully known, as the supply chains for different power generation options (fossil fuel generators, hydrogen-based fuel cells, small modular reactors, the local grid in the operating area, others) will each have different risks and advantages. Additionally, there are varying means of storing and distributing power on the battlefield.
Production Capacity by U.S. Allies and Partners	• Focusing on lithium supply for batteries, the White House 100-Day Review, completed in June 2021, assessed supply chain vulnerabilities across four key products including critical minerals and materials. According to the report, the most notable reserves are concentrated in Chile (44 percent), Australia (22 percent), Argentina (9 percent), China (7 percent), United States (3.5 percent), Canada (2.5 percent), and several other countries.[1] Production capacity is

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[1] The White House, *Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100-Day Reviews under Executive Order 14017*, June 2021.

	dominated by Australia, Chile, Argentina and China, and forecasts show that Australia will remain the leader. • Midstream and downstream activities of the lithium-ion battery supply chain are currently dominated by China. According to an assessment by the Federal Consortium of Advanced Batteries (FCAB), China is projected to hold 73 percent of the cell manufacturing capacity in 2025 based on pipeline and commissioned projects.[2] After China, Europe is expected to hold 13 percent of the cell manufacturing capacity in 2025 and has been developing policy initiatives and programs to counter China's dominance and localize supply chains within their own regions. Korea and Japan follow with 3 percent and 2 percent of the manufacturing capacity in 2025 respectively.

Hydrogen

Hydrogen may either be burned directly as a replacement for liquid fuels in an internal combustion engine (ICE) or used as a fuel in a fuel cell to power electrified systems. A highly efficient hydrogen ICE engine can achieve efficiencies nearing 40 percent, but produces nitrogen oxide emissions equivalent to a gasoline/diesel ICE. Fuel cells have efficiencies of around 60 percent and release no harmful emissions or carbon dioxide.[3] This is compared to 35 percent efficiencies in diesel or jet fuel ICE military land platforms.

Hydrogen production technology is well understood and can include direct electrolysis of water, electro-oxidation of ammonia, steam reforming of natural gas, or partial oxidation of fossil fuels. The production of hydrogen directly from fossil fuels would allow the Department to utilize the current jet fuel supply chain. The production of hydrogen is energy intensive and inefficient but the opportunity to organically produce near the point of use has considerable logistical and operational advantages. However, depending on the feedstock and the large amount of energy required to create hydrogen, production at forward bases could face similar supply chain challenges or the need to develop novel power generation sources to power the conversion process. In addition, there is a global lack of hydrogen storage and transportation infrastructure that matches the infrastructure for petroleum. The unique temperature, pressure, and corrosive properties of hydrogen complicate the buildout of such infrastructure both within the U.S. and globally.

Hydrogen Benefits, Risks, and Production Capacity by U.S Allies and Partners	
Performance Benefits and Reduction in Operational Energy Demand	• Reductions in operational demand may occur if hydrogen-based fuel cells were used to power fully electric forces. In that scenario, hydrogen would enable a reduction in operational energy demand of 25 percent.

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[2] U.S. Federal Consortium for Advanced Batteries, *National Blueprint for Lithium Batteries*, June 2021.

[3] U.S. Department of Energy, Energy Efficiency and Renewable Energy Office, *Fuel Cells Fact Sheet*, November 2015.

	- Transportation benefits (efficiency and safety) exist when hydrogen can be produced in a forward deployed location, but this requires energy and feedstocks for a mobile fuel production system.
Feasibility and Technology Availability	- Fuel cell technology has advanced to the point that they are commercially available and can be readily adapted to military use for multiple air and land platforms, particularly for unmanned systems.
Transportation Safety, Storage, and Supply Chain Risks	- While hydrogen is non-toxic and disperses more rapidly than other flammable fuels in inadvertent releases to the environment, the compound can ignite across a wider range of concentrations and has a lower ignition point than jet fuel, gasoline, or natural gas.[4] - Due to relatively low volumetric energy density, hydrogen is stored and distributed as a gas under high pressure or stored as a liquid at extremely low temperatures. Compared to petroleum, these requirements increase cost and complexity. - Hydrogen itself is corrosive and can degrade the strength and longevity of existing pipelines. Possible mitigations are being explored (e.g., blend with natural gas) but would themselves add complexity and cost, and not necessarily support DoD missions.[5] - Safety and supply chain risks are being addressed by private industry and can be applied directly to military operations. - If hydrogen is produced near the point of use to avoid distribution and/or storage, supply chain risks will depend on the source(s) of energy for the hydrogen generation process and the availability of the required feedstock(s). - Current R&D in hydrogen storage and transportation is focused on binding to inert powders and/or metallic materials to enable higher density storage, more efficient ingress/egress into storage, and safer transportation.
Production Capacity by U.S. Allies and Partners	- Currently, hydrogen is produced mainly from fossil fuels (70 percent), as a by-product in refineries (21 percent), and from fossil fuels with carbon capture and utilization (nine percent). For hydrogen to expand production capacity to foster demand in new sectors like transportation, it is critical to develop low-carbon hydrogen production routes including fossil fuels coupled with carbon capture, utilization, and storage (CCUS) and electrolysis.[6] - Fossil fuels with CCUS is currently the main low-carbon hydrogen production method. Currently there are 4 production

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[4] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office, *Safe Use of Hydrogen*.

[5] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office, *Hydrogen Pipelines*.

[6] International Energy Agency, *Hydrogen*, November 2021.

	facilities located in North America and close to 60 projects around the world are planned or in development, mostly in Europe, China, and Australia.[7] • Electrolysis, which produces hydrogen from electricity and water, currently accounts to ~0.03 percent of all hydrogen produced or 30 kt per year. Europe has 40 percent of global installed capacity and will remain the dominant region driven by increased policy support as reflected in the EU hydrogen strategy.[8] • Japan is focused on fossil-fuel based hydrogen supply chains, but has the goal to establish the manufacturing base for a supply chain based on renewable sources by 2030. Currently, Japan is involved in several hydrogen supply chain-related projects with different countries around the world including: fossil-fuel based ammonia from Saudi Arabia, natural gas–based hydrogen from Brunei, and lignite-based liquefied hydrogen shipment from Australia.[9]

<u>Sustainable Aviation Fuels</u>

Sustainable aviation fuels (SAF) are drop-in compatible replacements for petroleum based jet fuels. In coordination with engine and aircraft original equipment manufacturers, fuel producers, and governments, ASTM International evaluates low carbon fuels (feedstock + pathway), when comprising no more than 50 percent of the total fuel blend, are fully compatible with aircraft, and compatible with storage and distribution infrastructure. In turn, the Department has qualified the use of four alternative fuels approved for commercial use, and is qualifying additional SAF pathways in FY 2022 to ensure the Department can use all currently approved SAF pathways.

SAF Benefits, Risks, and Production Capacity by U.S Allies and Partners	
Performance Benefits and Reduction in Operational Energy Demand	• While SAF provides no efficiency improvement in the use of fuel and thus no effect on the demand for energy, SAF does offer considerably lower carbon emissions than petroleum.
Feasibility and Technology Availability	• While ASTM approval of seven SAF pathways suggests the feasibility of producing SAF using a range of different approaches and feedstocks, the primary challenge is the availability of SAF. • Over the near- to mid-term, SAF availability will be severely constrained. While production is increasing, U.S. production of SAF in 2021 totaled only 5 million gallons of SAF, or less

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[7] *Ibid*

[8] *Ibid*

[9] Nakano, Jane, *Japan's Hydrogen Industrial Strategy*, Center for Strategic and International Studies, 21 Oct 2021.

	than 1 percent of total U.S. jet fuel use in the same year.[10] Additional production facilities are under construction in the U.S. (including two facilities funded by the Defense Production Act), but future production from these facilities has already been purchased by airlines and other users. The Department will compete with airlines and other buyers for limited volumes of SAF. • According to the inter-agency SAF Grand Challenge goal for 2030, the U.S. will seek to produce 3 billion gallons of SAF, or ~10 percent of total jet fuel use in the U.S. by 2030 and 35 billion gallons by 2050, or nearly 90 percent of predicted jet fuel use.[11] • The relatively high price of SAF limits the Department's ability to acquire SAF. Per 10 U.S.C. § 2922h, the Department can only procure alternative fuels when cost competitive with petroleum, unless the Secretary of Defnese issues a waiver of that requirement. While the Department is postured to use multiple approved SAF pathways, the limited worldwide availability of SAF and the resulting high prices may constrain the Department's ability to procure these fuels.
Transportation Safety, Storage, and Supply Chain Risks	• If not produced locally, the supply chains for SAF – a heavy bulky liquid required in volumes generally similar to jet fuel – will be generally similar to those of petroleum-based jet fuels. This is particularly true for deployed forces when Department logistics forces are distributing liquid fuels for end use by the warfighter. The introduction of SAF fuels will require additional blending, storage, and certification requirements to ensure fuel quality that can increase the supply chain costs • If produced locally, SAF supply chains would have reduced risks of distributing the final product, but may face risks related to the power needed for the refining process and the availability of feedstocks. Research initiatives are underway to explore the production of SAF from a range of feedstocks, including air and seawater, but require large amounts of power to produce relatively small volumes of fuel. Blending, additives, aromatics and certification requirements will have to be addressed locally. • Additional analyses are required to determine the relative changes in supply chain risk for these different approaches to SAF production.

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[10] Brown, Nate and Anna Oldani. *Sustainable Aviation Fuels (SAF): Update to FAA REDAC E&E Subcommittee*. Federal Aviation Administration. 22 Mar 2022. Jet fuel use in the U.S. totaled 500,475,000 barrels in 2021. US Energy Information Administration. *Petroleum & Other Liquids – Product Supplied - Kerosene-Type Jet Fuel – 2021*. 29 Jul 2022.

[11] U.S. Department of Energy, Bioenergy Technologies Office. *Sustainable Aviation Fuel Grand Challenge*.

Production Capacity by U.S. Allies and Partners for Fuel Alternatives	• Overseas investments in SAF are growing driven by mounting pressure from government mandates and directives from the global aviation industry, which have resulted in exponential growth of planned production facilities, going from eight operating sites to 62 announced facilities distributed across the world as of April 2022.[12] • In Europe, the growth is led by the United Kingdom, Sweden, France, Netherlands, and Italy with 4 or more facilities announced for each of these countries. Germany, Austria, Poland and Norway follow with one-two facilities announced per country. In Asia, Japan leads with four new facilities announced for the coming years, followed by China with three, Indonesia and Korea with two, and Singapore and Philippines with one.[13]

Research and Development Recommendations to Address the Demand Side of the Contested Logistics Environment

To identify research and development investments in operational energy needed to deploy and sustain joint forces in contested operating environments, the Office of the Secretary of Defense (OSD) sponsored a series of analytic studies to assess joint operational energy gaps in the near (1-5 years), medium (5-15 years), and far (15-plus years) terms and identify the science and technology (S&T) initiatives needed to fill them. After integrating inputs from the Services, Combatant Commands, and OSD, the studies identified capability gaps and proposed future research and development investments in the *DoD Operational Energy Science and Technology Strategy*. The strategy includes three focus areas: Powering the Force, Electrifying the Battlespace, including the Space and Cyber Domain, and Commanding Energy.

The "Powering the Force" focus area seeks to support the deployment of more mobile and distributed operations with more agile logistics, to reduce the risk of carrying fuel to the fight, especially through contested environments. Recommended S&T investments include:

- Near-term: Integrate hybrid-electric platform power into standardized tactical micro-grids; ruggedize portable renewables and energy harvesting technology alongside distributed battery energy storage; decrease the detectable signature and criticality of fuel movers and storage.
- Mid-term: Develop safe fuels for tactical nuclear power; predict variations in renewable energy resources; develop ruggedized storage and distribution of alternative fuels.
- Long-term: Enable resilient and flexible networks of battlefield energy distribution; pursue next-generation platform propulsion.

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[12] Argus Media. *Global SAF Capacity Map*. April 2022.

[13] *Ibid.*

The “Electrifying the Battlespace, including the Space and Cyber Domain” focus area seeks to enable the electrification of weapons, platforms, unmanned systems, and personnel to field new weapon, sensing, active defense, and other technologies; advance power and thermal management technologies to meet the growing demands of high-power systems; and pursue potential game-changing technology that drastically reduces energy resupply risks, costs, and signatures that are prevalent in the contested logistics environment. Recommended S&T investments include:

- Near-term: Improve ruggedized battery performance, to include standardization and safety; develop hybrid systems that include electrical propulsion; reduce the weight of personally carried batteries; improve the efficiency, reliability, and performance of wireless power-beaming receivers and integrated systems.
- Mid-term: Build fully integrated analytical tools for platform thermal management development; modularize high-power, multipurpose large-scale energy magazines; demonstrate high-power, fast-switching, pulse-forming networks; demonstrate ground-based power beaming deployed with unmanned systems and unattended sensors.
- Long-term: Demonstrate adaptive power and energy controls on platforms and soldiers; perform autonomous energy transfer and optimization among unmanned systems; demonstrate space-to-ground and ground-to-air-to-ground power beaming.

The “Commanding Energy” focus area seeks to improve understanding of energy operating profiles and transition the Joint Force from a reactive to a predictive posture for energy management and control. Recommended S&T investments in this area include:

- Near-term: Integrate operational energy into mission modeling tools, wargaming, and personnel development; develop understanding of adversary energy use.
- Mid-term: Demonstrate real-time metering and monitoring of fuel use and storage levels; provide commanders at all levels near-real-time understanding of their energy status to include basing, platforms, and weapons; develop the ability to deny, destroy, or commandeer adversary energy systems.
- Long-term: Distribute network energy status and energy consumption prediction information across deployed forces; utilize machine learning/artificial intelligence for offensive and defensive energy optimization within and between platforms and weapon systems; demonstrate the ability to deny, destroy, or commandeer adversary energy systems.

Conclusion

In response to the request for a report in House Report 117-118, accompanying H.R. 4350, the National Defense Authorization Act for Fiscal Year 2022, the Department evaluated alternatives to petroleum based on the level of suitability, effort, and risk; potential performance benefits and corresponding operational benefits; current and future production capacity by U.S. allies and partners in the U.S. Indo-Pacific Command area of responsibility; and transportation safety and storage capacity.

These opportunities and insights will shape the development of the updated *Operational Energy Strategy* due to Congress in February 2023 and inform decision-making across the Department's planning, programming and budgeting processes.