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The Need for Speed: The Case for Continued Development of Hypersonic and Directed Energy Weapons

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ABSTRACT

As the People's Republic of China (PRC), and to a lesser extent Russia, rapidly develop and field hypersonic and directed energy weapons, the United States (US) faces a strategic military capabilities gap. The PRC's arsenal of hypersonic weapons extends its anti-access area denial capabilities throughout the South China Sea, increasing the required standoff distances for US military forces to operate in a conflict safely. To prevent the PRC from reshaping the liberal world order, the US should continue to develop offensive and defensive hypersonic and directed energy weapons to complement its current arsenal while addressing defense industrial base issues, including infrastructure, supply chain, and human capital, and fostering cooperation with allies and partners.

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EXECUTIVE SUMMARY

As the People's Republic of China (PRC) and Russia attempt to upend the liberal world order and minimize the United States' (US) presence and influence abroad, the US must embrace and develop emerging technologies to counter, compete, and, if necessary, defeat them. These emerging technologies include weapons systems, such as hypersonic weapons (HSW) and directed energy weapons (DEW), which, while not a solution to every challenge, do enhance the current conventional arsenal, improve its defensive capabilities, and offer a credible deterrent alternative just below the nuclear triad. When looking through the lens of potential conflict with the PRC over Taiwan, HSWs provide the offensive capabilities to help mitigate the PRC's anti-access area denial strategy to push US and allied forces further away from the conflict zone, thereby limiting their responsiveness and impact. HSW and DEW also provide enhanced defenses for the US at home and abroad against the PRC's growing conventional and nuclear enterprise.

The development of HSW and DEW has its challenges, however. The US defense industrial base (DIB) lacks the number of firms necessary to research, develop, and produce HSW and DEW, the requisite supply chains to provide the necessary raw materials and components, and the infrastructure to adequately test these weapons. The decline in the workforce and the continued lack of diversity across the industry impede the ability to meet current requirements and stifle innovation. Collectively, these issues have exacerbated the development and fielding of HSW and DEW for operational use and are partially responsible for the current high production costs.

The above challenges are significant but not insurmountable. This report provides recommendations to develop specific requirements for HSW and DEW to deliver a consistent

demand signal to the industry on the current and future requirements. Focusing on securing the supply chain and infrastructure shortfalls while addressing systemic human capital issues will improve the DIB. Working with partners and allies across all these areas will lower the current HSW and DEW production costs and better define the collective development requirements. Finally, the government must work with industry and academia to address and incorporate these recommendations. However, if the above issues are not addressed, it will allow the PRC to maintain and grow its asymmetric advantage and potentially dictate what happens next.

Summary of Challenges

- Chinese and Russian Development and Fielding of HSW
- US Development Requires Reconstituting Industrial Capacity and Human Capital
- Competition Among Programs for Funds, Labor, and Infrastructure
- Exorbitant Costs of HSW
- Budget Uncertainty
- Multiple Stakeholders with Competing Interests
- Innovation Ecosystem
- Talent Management – Recruiting and Retaining Skilled Labor
- Securing Globalized Supply Chains
- Ethical, Legal, Environmental, and Humanitarian Concerns

Summary of Recommendations

- Continue Developing HSW & DEW
    - HSW Defenses – HSW & DEW Capabilities
    - Establish DEW Joint Transition Office
    - Continue to invest in lower cost options
- Address Infrastructure and Supply Chain
    - Infrastructure Investment – Testing and Surge Limitations
    - Exotic Material & High-temperature Component Investments
    - Commercialization Efforts
    - Legislative/Executive Branch Efforts
- Grow Workforce in Emerging Technologies
    - Invest in STEM / Manufacturing Pipelines
    - Immigration
    - Diversity and Inclusion Initiatives
- Leverage allies and partners
    - Joint Research, Development, & Testing
    - Cost-Sharing Measures
    - Diplomatic & Transparency Efforts

INTRODUCTION

The Biden administration's 2022 National Security Strategy (NSS) states that the military's primary responsibilities are to: defend the homeland; deter attacks and aggression against the United States (US), our allies, and partners; and be prepared to fight and win the Nation's wars.[1] After two decades of military operations in Iraq and Afghanistan eroded American military and defense industrial advantages, the US military is challenged to meet this primary mission. The People's Republic of China (PRC) has capitalized on a US lack of strategic focus and rapidly invested in, developed, tested, and fielded hypersonic weapons (HSW) and directed energy weapons (DEW), dramatically advancing their military capabilities and anti-access area denial (A2/AD) strategy.[2] To deter China from attempting to reshape the liberal world order, the US should develop HSW and DEW for offensive and defensive capabilities to complement its current arsenal while addressing defense industrial base (DIB) issues, including infrastructure, supply chain, and human capital, and fostering cooperation with allies and partners.

Purpose and Organization

This paper analyzes US requirements to develop HSW and DEW, challenges to building the required supporting defense industrial base, and the necessity of mutually beneficial efforts with partners and allies. It comprises seven sections: the Strategic Environment, Stakeholder Interests, Structure-Conduct-Performance model, Factor Conditions, Supporting Industries and Supply Chains, National Security Implications, and Policy Recommendations.

Methodology

This paper summarizes information gained from engagements with experts from academia, industry, and the government across the HSW and DEW enterprise. Students also read

numerous articles, reports, and studies which provided additional background and supporting information. Students participated in the Weapons Industry Analysis course that provided the tools, frameworks, and vocabulary to understand and evaluate firm behavior, focusing on policy implications to meet national innovation and defense industrial base requirements in the context of strategic competition. Throughout the course, students conducted research on six companies with significant ties to HSW and DEW: Boeing, Leidos, Lockheed Martin, Nammo, Northrup Grumman, and Raytheon. Lastly, each student researched and wrote an individual paper on topics related to the hypersonic and directed energy fields.

Scope

Every attempt was made throughout this paper to provide an accurate, in-depth, and comprehensive analysis of the issues related to HSW and DEW. Several academic limitations prevented a more thorough assessment of the provided information. The first challenge encountered was program classification. The weapons programs studied in this course have many aspects that are classified. The paper is limited solely to unclassified reporting, leaving a significant portion of the research data inaccessible for student analysis. The second challenge is a lack of verifiable and accurate information from Russia and China on the status of their HSW and DEW programs. These programs also fall under their own strict national classification requirements, making them unavailable for review.

STRATEGIC ENVIRONMENT

The PRC and Russia lead the US and the world in developing HSW.[3] The NSS and the Department of Defense (DoD) National Defense Strategy (NDS) make addressing the PRC and Russian attempts to upend the liberal world order an imperative.[4,5] As Russia wages war on the European continent and the PRC continues to militarize the South China Sea (SCS), both nations have a strategic interest in HSW and DEW to enhance their A2/AD capabilities, threaten their neighbors, and deter US intervention.[6]

HSW and DEW Capabilities

HSWs fly at speeds of at least Mach 5, five times the speed of sound, and fall into two main categories: hypersonic cruise missiles (HCM) and hypersonic glide vehicles (HGV).[7] HCM are powered by air-breathing scramjet engines that propel the missile at hypersonic speeds.[8] HGV use a rocket motor to accelerate the missile to a high altitude and airspeed and then glide to their target.[9] Three main characteristics make these hypersonic missiles attractive to modern militaries: speed, range, and survivability.[10] Flying at Mach 5 is the equivalent of covering one mile per second, allowing the US to reach fleeting targets of opportunity much faster than current missiles.[11] HSWs also typically offer greater ranges than their subsonic and supersonic counterparts.[12] Finally, hypersonic missiles have increased weapon survivability, operating at altitudes far below traditional intercontinental ballistic missiles (ICBM) flight profiles but above the altitudes of most modern air defense systems.[13] HSWs are also highly maneuverable and fly less predictable flight paths than current ICBMs.[14]

The 2022 NDS identified directed energy as a technology that will significantly impact US national security.[15] Two common DEWs are high-energy laser (HEL) and high-powered microwave (HPM) weapons.[16] DEWs use concentrated electromagnetic energy to incapacitate,

damage, or destroy enemy equipment, personnel, or facilities.[17] Despite the maneuverability of HSWs, DEWs provide a cheaper and larger magazine depth option than conventional intercept missiles.[18] Compared with traditional munitions, DEWs offer similar lower costs per shot, a smaller logistical tail, and a deep magazine.[19]

US HSW Programs

The US Army, Navy, Air Force, and the Defense Advanced Research Projects Agency (DARPA) have multiple HSW programs under development.[20] The Army has the Long-Range Hypersonic Weapon (LRHW), a ground-launched boost-glide missile.[21] The Navy has two programs: the Intermediate-Range Conventional Prompt Strike (IR-CPS), a sea-launched boost-glide missile, and the Hypersonic Air-Launched Offensive Anti-surface Warfare (HALO), an air-launched cruise missile.[22] The Air Force also has two programs: the Air-Launched Rapid Response Weapon (ARRW), an air-launched boost-glide missile, and the Hypersonic Attack Cruise Missile (HACM), an air-launched cruise missile. Finally, DARPA has three additional programs: the Hypersonic Air-Breathing Weapon Concept (HAWC), which is cruise missile technology; the Tactical Boost Glide (TBG), a boost glide vehicle demonstration program; and the Operational Fires, a ground-based hypersonic boost-glide system.[23] The US also has two counter-HSW programs under development.[24] The Missile Defense Agency's (MDA) Glide Phase Interceptor (GPI) and DARPA's Glide Breaker are designed to target hypersonic missiles during their glide phase.[25] Developing capable HSW offensive and defensive systems is critical to supporting the NSS military requirements of defending the homeland and deterring attacks against the US and its allies and partners.[26]

US DEW Programs

The DoD also has several DEW programs in development.[27] These US Army, Navy, and Air Force HEL programs consist of ground, air, and sea-based technologies designed to provide short-range air defense (SHORAD); counter-unmanned aircraft systems (C-UAS); and counter-rocket, artillery, and mortar (C-RAM) missions.[28] DoD HPM weapons under development will provide non-kinetic methods to disable or destroy enemy communication and electronic systems. In combination with defensive hypersonic missiles, DEW will give the US military a comprehensive family of systems to deter and, if necessary, defeat the PRC and Russia.

The PRC HSW Programs

The PRC has significantly invested in HSW technology, believing these weapons are vital to gaining and maintaining supremacy in the SCS.[29] In addition to their DF-41 ICBMs, which reach hypersonic speeds on reentry, they also have several dedicated HSW programs.[30] The DF-17 is a medium-range ballistic missile designed to carry the conventional or nuclear-armed DF-ZF HGV.[31] A second PRC hypersonic program is the Starry Sky-2, a nuclear-capable hypersonic vehicle.[32] These HSW systems will significantly strengthen the PRC's already considerable A2/AD capabilities.

The PRC DEW Programs

The PRC has been developing DEW for over 40 years, making steady progress in developing HPM and progressively more powerful HEL systems.[33] The PRC has reportedly developed a 30-kilowatt mobile HEL, the LW-30, and is developing an airborne HEL pod to target unmanned aircraft and precision-guided munitions.[34] The PRC is also developing DEWs designed to degrade or damage optical and non-optical enemy satellites and their sensors in low-

earth orbit.[35] Combining capable DEW with HSW will allow the PRC to degrade US intelligence efforts and significantly threaten US forces in the Indo-Pacific region.

Russian HSW Programs

Russia prioritizes developing and fielding HSW to defeat US missile defense systems. As Russia's conventional forces have been degraded during the war in Ukraine, it leans even more heavily on its nuclear apparatus and other strategic weapons, such as its HSW program, for deterrence.[36] Like the PRC, Russia declared that its HSW could carry conventional and nuclear warheads on several delivery vehicles. Russia has several HSWs, the Kinzhal, Tsirkon, and Avangard, designed to strike key command and control centers.[37] In 2021, Russia successfully tested the first-ever underwater hypersonic missile launched from the Severodvinsk submarine.[38] This monumental test moves Russia closer to having operational HSWs capable of being launched from the air, land, or sea.

Russian DEW Programs

Russia has researched DEW since the 1960s, prioritizing HEL.[39] The Russian military has made significant progress in developing, fielding and deploying a ground-based HEL, the Peresvet, with several mobile ICBMs.[40] The capabilities of the Peresvet are not widely known, but analysts assess that it will be able to degrade satellites and defend against unmanned aerial systems.[41] Russia continues to develop the Peresvet, hoping to increase its power output and deploy it on military aircraft.[42] In addition to its HEL systems, Russia is also developing HPM systems to use against enemy satellites.[43] Russia's ultimate goal in pursuing HSW and DEW is to limit the US and the North Atlantic Treaty Organization's (NATO) ability to gather intelligence while providing offensive weapons capable of penetrating US defenses and restoring its strategic stability.[44]

STAKEHOLDER INTERESTS

Key stakeholders in the HSW and DEW realm include the US government, military services, defense contractors and industry partners, allies and partners, potential adversaries, academia and research institutions, international organizations, non-governmental organizations (NGOs), media, and the public (Appendix A). Their diverse interests, concerns, and priorities influence the direction and speed of developing and deploying these emerging technologies. According to the stakeholder theory, stakeholders are grouped into four categories based on their power over and interest in the industry: Key Players, Context Setters, Subjects, and the Crowd (Appendix B).[45]

Interests, Concerns, and Priorities

Key Players with high power and interest in the HSW and DEW industries include the US government, military services, defense contractors and industry partners, allies and partners, and potential adversaries. Actively engaging and consulting with these stakeholders throughout the processes to ensure their needs are met and their concerns are considered is crucial for success.[46]

Context Setters are characterized by low interest and high power. For the HSW and DEW industries, this category includes Congress. Although Congress has no direct involvement in developing or deploying these technologies, it can significantly influence industry and broader defense policy and controls the budget. Because of that, it is essential to keep Congress satisfied by providing information about critical developments and consulting them when necessary.[47]

Subjects consist of stakeholders with high interest but low power. This stakeholder group within the HSW and DEW industries includes academia and research institutions, international organizations, NGOs, and the media. Although those stakeholders may not have the authority to make decisions or to influence the industries' dynamics, their input is valuable, and their support can

help build momentum. Thus, Subjects should be kept informed, and their opinions should be considered.[48]

The Crowd is a group of stakeholders with low interest and low power. The public, which involves different sub-stakeholders such as individual citizens, local communities, and industry workers, belongs to this category because they do not directly affect the HSW and DEW industries and have little influence over the industries' outcomes. However, monitoring their opinions and ensuring they are informed about the industries' development is essential to maintain a positive image and minimize negative publicity.[49]

In the HSW and DEW industries, stakeholders' interests interact in diverse ways, impacting the development and deployment of these weapons. The interactions of stakeholders' interests can lead to convergence or divergence. [50] Converging interests drive technological superiority, operational capabilities, and national security, while diverging interests may hinder or alter the direction of technological development.

Managing Stakeholder Relationships

Establishing transparent and effective communication channels among stakeholders with convergent and divergent interests is essential in developing and deploying HSW and DEW. Open dialogue promotes trust and collaboration between the government, military services, defense contractors, academia, research institutions, international partners, NGOs, and the public. Transparent decision-making processes, which involve considering input from all relevant stakeholders, will also help solve problems, allowing the voice of all interested parties to be heard.

Encouraging cooperation and partnerships among stakeholders through joint research projects, cooperative agreements, and technology sharing can significantly contribute to advancing

the HSW and DEW industries. Fostering public-private partnerships, promoting international cooperation, establishing innovation hubs, and developing industry standards can help achieve this. Pooling resources and sharing expertise and knowledge enables stakeholders to overcome challenges, address concerns, reduce costs, and accelerate the development of advanced weapons systems.

Effectively managing relationships within the HSW and DEW industries requires addressing stakeholders' concerns and potential conflicts. To foster a cooperative environment and find mutually beneficial solutions, stakeholders can proactively identify and address issues, such as environmental, ethical, and financial, by implementing strategies like creating dedicated committees, developing monitoring mechanisms, and promoting shared ethical values. Additionally, adopting policies prioritizing these concerns, such as stricter environmental regulations, ethical guidelines for research and development (R&D), and cost-benefit analyses, can ensure responsible investments in these advanced technologies while maintaining transparency and building trust among all parties.

Finally, stakeholder relationship management efforts should include working with international organizations and other states to establish and strengthen norms and agreements in HSW and DEW. Such collaborative efforts can contribute to preventing an arms race, reducing proliferation risk, and fostering transparency and trust among nations. Ultimately, this cooperation would ensure that the development and deployment of these technologies are carried out responsibly, in compliance with international law, and adherence to humanitarian principles while addressing potential environmental, ethical, and safety concerns.

STRUCTURE-CONDUCT-PERFORMANCE

Aerospace and Defense Industry Analysis

The Structure-Conduct-Performance (SCP) model is a "framework for empirical analysis of the effect of market structure on industry performance."[51] The central hypothesis is that the "observable structural characteristics of a market determine the behavior of firms within that market, and the behavior of firms within a market determines measurable market performance."[52] Thus, understanding the market structure of an industry provides insight into a firm's behavior and overall market performance.

The following is an SCP review of the defense industries in the US, the PRC, Russia, and Norway. The review provides insight into emerging industries within the US aerospace and defense market, such as HSW and DEW, and highlights the opportunities and challenges that exist within the industries in relation to our adversaries and partners.

US Defense Industry

The US aerospace and defense market accounts for 45.2% of the global market value exceeding $441.4 billion in 2020, with an anticipated total of $616.9 billion by 2025.[53] However, the market is dominated by the four largest US aerospace and defense firms, Boeing, Lockheed Martin, Raytheon Technologies, and Northrop Grumman, which account for nearly 50% of the US aerospace and defense market.[54]

The DoD and its agencies are the primary buyers of domestically produced defense systems, including HSW and DEW. While foreign military sales are authorized, firms must adhere to strict transfer/sales regulations and seek approval from the Department of State. The DoD establishes technical standards, oversees procurement decisions, and controls exports, all of which substantially impact the conduct and performance of the industry. Moreover, competitors

within this monopsonistic market are further constrained by the burden of DoD annual funding requirements, fluctuating demand signals from the DoD, and congressional oversight.

High barriers to entry, such as high capital costs, arduous government contracting processes, regulatory requirements, and research and development costs, generally dissuade new entrants from joining the market. Consequently, constrained industry participation lessens competition which further reduces innovation. This is evidenced by the industry's rate of innovation being assessed as medium, based on the low number of new patents assigned, thereby reducing the likelihood of disruptive innovation occurring.[55] Rivalry within the aerospace and defense market is generally strong, with firms competing intensely for limited government contracts and funding.[56] However, product diversification within the larger organizations alleviates dependency on particular markets, relieving some rivalry amongst the larger firms.[57] Moreover, it is not uncommon for firms to collaborate through joint ventures or serve as subcontractors or suppliers to contracted primes.

The HSW and DEW industries are immature markets within the larger aerospace and defense market that require tremendous R&D before fielding.[58] While the DoD generally provides for the cost of R&D through contracting, competitors within this industry assume some financial risk in R&D and lost opportunity costs without guaranteed production contracts. Thus, a firm pricing strategy during R&D must account for the competitive nature of the bidding process and the possibility of failure, thereby driving up the cost to the DoD. Despite the challenges of the aerospace and defense industry, the US DIB is considered generally healthy, with efforts being made to increase resiliency in infrastructure, supply chain, and the workforce. The largest US aerospace and defense firms are profitable, with an average return on invested capital between 10-15%.[59]

The PRC Defense Industry

The PRC aerospace and defense market value was $118.4 billion in 2020, with an anticipated market value of $163.4 billion by 2025.[60] With the world's second-largest Gross Domestic Product (GDP), the PRC is positioned to continue to increase its defense spending and grow its DIB. Seven of the twenty largest defense-related firms in the world are Chinese firms.[61] The PRC aerospace and defense industry is primarily consolidated amongst a few state-owned and controlled conglomerates.[62] As such, the government controls domestic sales' pricing structure and foreign military sales regulations. Moreover, rivalry amongst firms is moderate due to government ownership.

High barriers to entry, such as high capital cost, government ownership, and regulatory requirements, generally prevent new entrants from joining the market. However, to stimulate innovation and create a self-reliant aerospace and defense industry, the PRC opened its defense industry to domestic private companies, with a portion of its budget being offered in support.[63] Utilizing a top-down approach, industry firms receive direction from military and civilian leaders. According to a 2021 Center for Strategic and International Studies report, “When specific weapons are deemed a national priority, top-level military and civilian leaders participate in extra oversight mechanisms to guide development.”[64] Thus, innovation is not born of competition or market forces but is directed by the government.

The exact profitability of the PRC aerospace and defense industry is difficult to determine since the firms are state-owned and are not required to disclose their financial information publicly. Notwithstanding the inability to verify the accuracy of market indicators and performance, the pricing structure of goods sold by state-owned Chinese companies is most likely substantially different than private companies in other defense industries.[65] Moreover, as

the GDP continues to grow, so does the PRC's purchasing power and its DIB. With a GDP currently nearing that of the US, the PRC's DIB is near parity with the US and could potentially surpass the US in the near future.

Russia's Defense Industry

With a market value of only $53.9 billion in 2020, Russia's aerospace and defense sector is considerably smaller than the US.[66] Given the volatility surrounding its war with Ukraine, market estimates for 2025 are not available. While the market is predominantly dominated by a few large companies, the Russian government controls nearly all of the defense industry directly or through equity shares.[67] As such, the entire industry is highly protected by the government. The Russian government and its agencies are the primary buyers of domestically produced defense systems accounting for 72% of all sales.[68] The remaining 28% is sold internationally. Russia is the second largest arms exporter, with over $15 billion in defense-related exports in 2020.[69] As indicated above, the government is the controlling shareholder in most of the firms. Thus, the government controls domestic sales pricing and foreign military sales regulations. Moreover, rivalry amongst firms is moderate due to government ownership.

High barriers to entry, such as high capital cost, government ownership, and regulatory requirements, generally prevent new entrants from joining the market. New participants wishing to join must partner with a government-owned organization and are subject to strict guidelines. As with the PRC, the exact profitability of the Russian aerospace and defense industry is difficult to determine since the firms are state-owned and are not required to disclose their financial information publicly. Additionally, the Russian government heavily subsidizes the industry, funding research and development and the production of weapons systems and military equipment. Thus, unlike the US, Russia's aerospace and defense industry is not necessarily

influenced by the market structure. Instead, the government guides the firms' behavior almost exclusively.

While Russia's defense firms are mostly free of the risks associated with competition, innovation is potentially limited by the lack of competition and the constraints of a limited federal budget. Although this has worked to restrict Russian innovation due to its relatively small GDP, Russia has been able to develop and field HSW and DEW.

Norway's Defense Industry

Norway's aerospace and defense market value was $4.5 billion in 2020, with an anticipated market value of $4.7 billion by 2025.[70] Norway's defense industry is relatively small and comprises only a handful of companies, but its market structure is unique within the defense industry, and warrants review. Norway employs a hybrid ownership system that garners the benefits of capitalism while providing the protections of state-owned industries. Centered around key players like Kongsberg Defense & Aerospace and Nammo, the Norwegian government is a 50% stakeholder in the industry.[71] Yet, unlike the PRC and Russia, the Norwegian government does not direct or mandate the conduct of the firms. Instead, Norwegian defense firms operate independently and are primarily focused on supplying products and services to the Norwegian Armed Forces and other international customers.

While the Norwegian government has been working to support the growth and development of the country's defense industry, the Norwegian defense budget is relatively small and incapable of supporting a truly robust defense industrial base.[72] Therefore, Norwegian firms competing in this market rely heavily on foreign military sales and, therefore, must compete with much larger defense firms. For example, Kongsberg, one of the larger Norwegian defense firms

and a supplier of advanced technologies, only generated 18% of its revenue from sales to Norway.[73] The remaining 82% of revenue was from international sales.

High barriers to entry, such as high capital costs and R&D costs, are common within the defense industry and generally dissuade new entrants from joining the market. However, Norway favors foreign direct investment to offset its budget limitations. With favorable regulations, an accepting culture, and a strong workforce, many foreign defense firms have established wholly-owned subsidiaries in Norway. Rivalry within the Norwegian aerospace and defense market is generally strong, with firms competing intensely for limited government contracts or international sales. To minimize rivalry, Norwegian firms tend to specialize in niche markets and seek partnerships with foreign firms to co-develop military goods, a practice that the Norwegian government fully supports.[74] Despite its small size, government policy and regulation have sufficiently incentivized Norway's aerospace and defense industry to compete at an international level successfully. By encouraging foreign military sales and international partnerships, the Norwegian government ensures that its aerospace and defense industry is both resilient and capable. Most importantly, Norway's approach to its defense industry encourages innovation within the industry while distributing the cost across the international community.

FACTOR CONDITIONS

To compete with the PRC and Russia's advances in emerging technologies including HSW and DEW, the US must invest in training and education programs to develop the diverse workforce required to engineer and manufacture these systems. The 2022 NSS stressed the importance of complementing "the innovative power of the private sector with a modern industrial strategy that makes strategic public investments in America's workforce and in strategic sectors and supply chains, especially critical and emerging technologies."[75] The US Senate Committee on Armed Services equally expressed concerns over workforce requirements, infrastructure, and the vitality of the national DIB to meet the challenges of emerging technology development.[76]

These workforce and infrastructure concerns are not new, however. In 2019, the National Science Board expressed similar concerns stating, "Technologically, we are on the cusp of … developments that will continue to accelerate changes in the workplace and intensify our need for citizens who excel at using data, information, and technology in their work. … We must "step up" our game and nurture and expand our domestic talent … if our workforce is to remain competitive."[77] While the US remains one of the strongest workforce competitors worldwide, the PRC and Russia have harnessed their respective labor force to achieve breakthroughs in emerging technologies. If the US wants to develop and produce HSW and DEW at scale to compete or gain parity with the PRC and Russia, it must grow the workforce in all sectors, especially manufacturing and engineering.

A 2023 article by Tony Schmitz advises, "Across America, industries are facing enormous supply-chain delays, worker shortages, and places to build due to several decades of offshoring and deemphasizing manufacturing research, education, and training in the US."[78]

According to the National Association of Manufacturers, "the number of open jobs in the manufacturing sector has roughly doubled since before the pandemic, and companies everywhere are struggling to find qualified candidates."[79] An estimated 2.1 million manufacturing jobs could go unfilled by 2030 due to skills gaps and retirements.[80] The US also faces a potential shortfall of more than 6 million engineers by 2024, negatively impacting new technology development and innovative approaches.[81] These shortfalls may be "driven in part by an aging workforce, declining interest in Science, Technology, Engineering, and Math (STEM) education, and engineers moving into non-engineering roles."[82]

Companies throughout the industry are seeing hiring shortfalls for various reasons. For example, Dynetics, a subsidiary of Leidos, headquartered in Huntsville, Alabama, competes with companies like Lockheed Martin, Boeing, Raytheon, and others for engineers and high-tech manufacturing experts as the workforce requirements rapidly grow across all companies.[83] Retention is also a challenge as employees often move between companies seeking the compensation and a corporate culture that fits them best.[84] Additionally, much of the manufacturing talent is nearing retirement eligibility and will take their decades of knowledge with them. To combat this, Dynetics and others pair these "grey beards" with young new hires to transfer the specialty knowledge they have gained over 35 plus years of experience that cannot be taught in a classroom.[85] In a tight market, firms also turn to immigration and specialty work visa programs to bring in talent from other countries and retain high-skilled immigrants within the US.[86] In April 2023, the American Council of Engineering Companies "asked the Biden administration to make changes in the H-1B and other federal workforce-related programs so employers can attract and retain more skilled professionals."[87]

For national security and economic well-being, the US must implement a strategic talent pipeline that promotes diversity and inclusivity in science, engineering, and the trades to advance US workforce requirements and the skilled technical workforce.[88] According to the National Science Board, "A diverse talent pool of STEM-literate Americans … will be essential for maintaining the national innovation base that supports key sectors of the economy, [makes] the scientific discoveries, and [creates] the technologies of the future."[89] To support this talent development, the industry must make a stronger push for increased STEM education programs starting in primary and secondary schools to drive early interest and introduce students to various emerging technology jobs. The US must also ensure the availability of education and training programs at all levels, from elementary and high school to technical certification programs, vocational programs and apprenticeships, and community college and university degree programs. Additionally, the industry must regularly define what skills are needed now and anticipate what skills will be required in the future to assist educators in building programs to develop the requisite workforce.[90]

Federal research shows that the skilled technical fields have the most diversity across the STEM-capable workforce; however, gender has the most significant disparity.[91] The skilled technical workforce is predominantly male, with less than 29% female workers.[92] The manufacturing industry is trying to change that through the Women MAKE Program, which recognizes and awards the accomplishments of women in manufacturing and is working to grow the population of women from 29% to 35% by 2030.[93] Another program that can bridge the gender gap is Nontraditional Employment for Women (NEW), based in New York City.[94] The mission of NEW is to create women-specific pipelines for electricians, ironworkers, operating engineers, maintainers, and skilled construction workers.[95] Over the past 40 years, "NEW has

increased the number of women represented in trade careers in NYC from two to seven percent, with many apprenticeships approaching or exceeding 15 percent women."[96]

As the future of manufacturing is highly technical, workers will need to be trained in the latest manufacturing tools and technologies.[97] Today's manufacturing systems are "networked for improved reliability and data collection, programmable for automation, and can shape metal alloys and composite materials into critical products."[98] The personnel operating these machines must be highly skilled, trained through technical schools and advanced on-the-job training, and able to fix any issue without inducing delays in manufacturing. To assist training efforts, the Office of Industrial Policy, through the DoD Industrial Base Analysis and Sustainment Program, is supporting America's Cutting Edge (ACE), a national initiative for machine tool technology development and advancement.[99] ACE offers no-cost online and in-person training in machining and measurement, teaching students to "program and operate computer-controlled machine tools while producing components for an oscillating piston air engine," skills that will translate to producing advanced parts for HSW and DEW.[100]

With a more than 6 million engineer shortfall looming, a renewed emphasis on STEM programs starting with K-12 schools will be critical to growing engineers of the future. However, the US needs future engineers today to develop innovative high-tech capabilities. The US must look to non-traditional methods to develop talent while developing technology. In response to the 2019 National Defense Authorization Act directing accelerated development of HSW, the Under Secretary of Defense for Research & Engineering and the Joint Hypersonics Transition Office created the University Consortium for Applied Hypersonics (UCAH).[101] The UCAH intersects government organizations, US, United Kingdom (UK), and Australian universities, the DIB, and national laboratories, with 293 participating entities supporting US government-funded

development projects.[102,103] The UCAH "aims to deliver the innovation and workforce needed to advance modern hypersonic flight systems in support of national defense."[104]

As advanced technology industries continue to grow rapidly, one major DoD concern is the national security implications of training and hiring non-US citizens. A growing number of students attending engineering programs in the US are from foreign countries. US Defense analyst C. Todd Lopez states, "Increasingly, the Department [of Defense] is finding that some faculty members and students have undisclosed ties to a foreign government that is incentivizing them to transfer that know-how or technology out of the US to a strategic competitor's military."[105] It is critical for the US government and the DoD to monitor university programs that may drive research in critical or classified technologies and ensure the appropriate protections are put in place to limit access to the information and prevent its distribution to foreign countries.

Teaming with some foreign countries, however, will be critical to advancements in future technologies, providing additional workforce and infrastructure resources. A February 2021 Senate hearing emphasized that the US integrated deterrence approach capitalizes on the strength of allies and partners.[106] Through AUKUS, the trilateral defense pact between the US, Australia, and the UK, the US has leveraged synergistic relationships enhancing workforce talent, knowledge-sharing, funding, and critical infrastructure. Australia's hypersonic flight-testing infrastructure at Woomera Range mutually benefits the US, Australia, and the UK, providing the needed resources to accelerate development.[107] Dr. Mike Lewis, Executive Director of the National Defense Industrial Association's Emerging Technologies Institute, said, "We've been doing most of our flight testing over the Pacific Ocean…whatever you're testing crashes into the ocean, and you don't get it back." At Woomera Range, "it lands on the desert floor, and you can pick it up. That's a tremendous value."[108]

SUPPORTING INDUSTRIES AND SUPPLY CHAIN

Like the workforce, the role of supporting industries and the requisite supply chain requirements in emerging technologies development cannot be understated. A robust network of suppliers is integral to providing the most cost-effective and timely products and galvanizing the type of competition which drives innovation and development of emerging technologies such as HSW and DEW. The interplay between the primary contractors charged with developing these weapon systems and the supporting industries which provide the necessary materials to construct them is critical to efficiently meet requirements. However, as was experienced during the Covid-19 pandemic and more recently as the US supplies Ukraine with weaponry while attempting to keep its stocks full, there are shortfalls throughout the DIB.

The conflict in Ukraine has taught the US and Western allies a valuable lesson about the vulnerabilities in the DIB. The consumption challenges in ramping up production lines for munitions and present-generation weapons systems have come to light. These issues correctly emphasize concerns that the DIB would likely struggle to meet the demands in a protracted conflict with the PRC over Taiwan while still supplying Ukraine for its war with Russia. For certain weapons systems such as HSW and DEW, there is only one buyer, the DoD, which characterizes the industry as a monopsony, resulting in fewer firms manufacturing these weapons and less competition.[109] This, in turn, limits the ability of the DIB to quickly ramp up production of these exquisite weapons systems if demand were to increase significantly. There are currently limited commercial applications for HSW and DEW, which has undoubtedly reduced the number of firms in the industry and driven higher costs.[110]

Even this explanation of the challenges facing the DIB is an oversimplification, given the highly specialized nature of major weapon systems such as HSW and DEW. From the over

200,000 government suppliers and manufacturers in the ecosystem writ large, there are less than 100 major weapons system developers.[111] Between fiscal year 2011 to 2020, the number of small businesses receiving contract awards decreased by 43%. Some of this resulted from the consolidation of contractors over the past few decades. This reduction explains why the DIB is shrinking overall and why more complex requirements are going to only a few larger contractors with less ability to surge production if required.[112]

In addition to these challenges, there are also supply chain concerns. In February 2023, President Biden directed his administration and the DoD to conduct a "100-day supply chain review of the US, and more specifically, the US defense industrial base."[113] The Administration rightly advised that a "resilient, diverse, and secure" supply chain was essential to the nation's prosperity and security.[114] The Covid-19 pandemic, and the ongoing war in Ukraine, brought these issues to light; however, they are not new. In fact, over the past several decades, the US has increasingly controlled less and less of its supply chains, relying heavily on other countries for many essential materials used in weapons manufacturing. While final production primarily happens in the US, the initial procurement of essential materials frequently comes from countries not aligned with the US, including the PRC, a problem that could become more dire if a conflict with the PRC erupts.

More specifically, the US relies heavily on minerals, approximately 51% of which come from other countries, to meet the nation's supply chain requirements. This includes exotic raw materials such as tungsten, titanium, silicon carbide, carbon-carbon materials, gallium nitride, and superalloys, all essential to developing and producing HSW and similar munitions. The US lacks the industrial depth and ability to mine the exotic and rare earth minerals required to mass produce these weapons. The current US mining permit process is part of the problem, with

extensive paperwork requirements and lengthy approval times before raw earth minerals can be extracted.[115] A report from the National Mining Association advised, "The US is import-reliant -- depending on imports for more than 50% of its consumption -- for 31 of the 35 minerals the US Interior Department designates as critical minerals, the report said. Of those critical minerals, the US has zero domestic production and completely relies on imports for all of its consumption of 14 minerals."[116]

Given the increasingly unstable global threat environment, the DIB's ability to mass produce HSW and DEW if required must be developed. The demand for efficient and secure supply chains within the US is imperative to meet future requirements. SpaceX, for example, has taken this into its own hands and vertically integrated many of its services.[117] By vertically integrating much of its supply chain, SpaceX controls key chokepoints and can rely less on the volatile sub-tier supplier level, allowing it to better meet internal and external timelines.[118] When President Biden invoked the Defense Production Act in March 2023, he intended to incentivize the DIB to increase the HSW production cycle from increased research and development to full-scale manufacturing.[119] This was an important step; however, without making additional adjustments now, the DIB cannot support immediate surge requirements for mass production of HSW or DEW in the event of a large-scale conflict with the PRC.

NATIONAL SECURITY IMPLICATIONS

When considering US national security implications, the development of HSW and DEW could impact strategic stability through their offensive and deterrent effects. Strategic stability is a term used in international relations to describe a state of affairs that aims to minimize all risks associated with deterrence failure. It can be understood as a state in which the postures, capabilities, and doctrines of great power competitors do not incentivize the first use of nuclear weapons in a crisis in which those states have an assured retaliatory capability and do not improve their relative position by increasing strategic arsenals, qualitatively or quantitatively.[120]

The 2022 NSS named the PRC as the US's "most consequential geopolitical challenge."[121] This attestation came with a sense of urgency, declaring the following "ten years as being the decisive decade"[122] to "strengthen and utilize the military"[123] as a means to deter the PRC who, "unconstrained by arms control agreements such as the Intermediate-Range Nuclear Forces Treaty, has been testing and producing numerous types of missiles to include hypersonics and thereby enjoys a commanding lead over the US in this area."[124] Historically, the People's Liberation Army's (PLA) military doctrine relied heavily on "numerical advantage against a Taiwan-backed U.S. response to an invasion scenario."[125] However, after witnessing US success during Operation Desert Storm in the early 1990s, the PLA began modernizing its military towards technology-driven capabilities, starting with improvements to their industrial base with a focus on airpower and precision-guided munitions. Additionally, given the maritime environment encapsulating China and Taiwan, improvement to their naval forces was on order, as well as the development of hypersonic missiles to stymie a US-led response to an invasion in Taiwan.

The PRC's HSW program serves as a national strategic goal of deterrence and coercion and provides tactical-level solutions in the event of a conflict. The focus of the PRC HSW is aimed directly at the US as well as its Pacific allies and partners, "whom Beijing seeks to deter from interfering in portions of the Western Pacific that it sees as a privileged sphere of influence."[126] The PRC is betting on its ability to counter any intervention using HSW as the capability that extends its A2/AD at ranges problematic enough to raise the US cost calculation. Additionally, the PRC HSW can provide tactical enabling capabilities to realize a quick seizure or fait accompli against Taiwan via preemptive attacks against US forces within proximity of the first and second island chains.

Another consideration is the threat of a conventional HSW strike against targets in the US. Shaan Shaikh, a defense analyst with the Center for Strategic and International Studies, states, "While China can strike the United States with its nuclear-armed ballistic missiles, non-nuclear hypersonic weapons would offer China a less escalatory way of attacking the United States."[127] The US may wrestle with the risk potential in an escalatory nuclear counterstrike, giving the PRC time and perhaps justification for subsequent nuclear provocation. Of course, if the US were to begin fielding its HSW, the PRC, in turn, would become equally vulnerable, thereby negating the effectiveness of such a strategy.

If conflict were to start with the PRC, the ability to quickly strike key targets, such as A2/AD systems, command and control (C2) nodes, and strategic weapons systems, would be critical. As the Congressional Budget Office (CBO) reported, HSWs distinguish themselves from other weapons in the arsenal because they can strike these opportunity-cost targets much faster while giving the adversary less time to react.[128] CBO concluded that in A2/AD scenarios against the PRC or Russia, there would probably be many time-sensitive, high-value targets for which

rapid strikes from longer distances could be useful.[129] The PRC is worried the US might be tempted to use its HSW to preemptively strike its nuclear forces and C2 apparatus. As such, in the PRC's mind, HSW will impact existing strategic stability among major powers because they have the potential to break the current nuclear/conventional boundary.[130]

In addition to its potential offensive capabilities, HSWs could offer a credible deterrent alternative just below nuclear weapons if developed and fielded in high enough numbers. The 2022 NDS describes its continued Deterrence by Denial strategy and championed not only nuclear weapons but also HSW and DEW to deter aggression from adversaries attempting to rapidly seize territory.[131] Currently, however, the US does not yet have enough HSW and DEW in the field to deter its adversaries, particularly the PRC and Russia, who have not only fielded HSW but, in Russia's case, have used them on the battlefield.[132]

When the US does develop HSWs in sufficient numbers, numerous iterations spawning from the interplay between the US, the PRC, and Russia could play out as they act and react to each other's advancements. A level of deterrence will exist by simply having this capability. Since the US has outwardly proclaimed that its HSWs will only be armed with conventional warheads, their deterrent effect is increased, allowing the US to use them without inciting fear of nuclear escalation. This is not the same for the PRC or Russia, who have stated their HSWs will be dual-use, thereby limiting their use against other nuclear-armed countries. Unless the PRC or Russia identify their HSW launches as containing conventional warheads, the state on the receiving end may interpret it as a potential nuclear launch and respond accordingly. Additionally, if DEWs were proven effective at defeating HSWs and the PRC or Russia felt they could no longer penetrate the US defense systems, they may refrain from using them and de-escalate or potentially choose to escalate to traditional nuclear weapons.

POLICY RECOMMENDATIONS

Several challenges impacting HSW and DEW development were noted throughout this report. The following recommendations offer potential avenues to address these limitations as well as ways to enhance HSW and DEW development in the future.

Recommendation 1: Continue Developing HSW and DEW

Issue: The US has no fielded HSW capability, limited DEW capability, and limited defensive capability against HSW.

A. Offensive/Defensive HSW / DEW capabilities: The US is not in an HSW arms race with the PRC or Russia; however, it will need to further develop multi-domain HSW to support the NSS and NDS to defend, deter, and outcompete the PRC and Russia. To penetrate heavily guarded A2/AD environments and strike time-sensitive targets, the development of air, sea, and land-based HSW is critical. Although the US may be "behind" the PRC and Russia in fielding HSW, the US has several programs under development. The Pentagon's 2024 budget proposal requests $11 billion to deliver a mix of hypersonic and long-range subsonic missiles, fund initial all-domain hypersonic capability, and buy 24 HSWs.[133] The DoD should continue to prioritize and fund multi-domain hypersonic offensive strike capability at current or increased levels.

Vital to the US's ability to defend the homeland is a more advanced defensive capability to meet the challenges posed by HSW. This will require developing key technologies designed specifically to defeat HSW, such as GPI, HPM technology, and HEL capabilities. GPI is designed to defeat a hypersonic missile in the glide phase before the missile enters maneuverable flight.[134] The MDA has provided $41 million to Raytheon and Northrup Grumman to continue the GPI program and requested $209 million for new interceptors and upgraded Aegis weapon

systems.[135] The DoD should continue to fund GPI at current levels and increase R&D funding for directed energy defensive systems.

HPMs, which travel at the speed of light, can potentially destroy, disrupt, or confuse the internal electronics of HSWs. HELs, which also travel at the speed of light, have relatively low operating costs and a theoretical "unlimited" magazine to defeat various air threats, including HSWs. It is estimated that a 1000kW laser is required to defeat a hypersonic missile in its boost phase.[136] Both HPM and HEL systems offer low operating cost alternatives based on their unlimited magazines, and the DoD should continue to fund their development at current levels.

B. Establish DEW Joint Transition Office: The DoD must orchestrate a more comprehensive and authoritative DEW transition plan well beyond the fidelity of the Office of the Secretary of Defense's 2020 Directed Energy Road Map. One feasible approach is establishing a Joint DEW Transition Office (JDETO) as the lead integrator for operationalizing DEW capability (Appendix C). This office would develop, implement, and monitor a comprehensive DEW roadmap that spans the entire DoD enterprise. The Services would be responsible for providing their respective DEW transition plans to JDETO, who would determine which capability gaps each technology will address. Additionally, JDETO would arbitrate specific roles and missions for DEW employment if consensus could not be reached among the Services.

C. Continue to invest in lower-cost options: Quantity is a quality unto itself. To defend, deter, and out-compete the PRC and Russia, the US must continue to leverage its current cruise missile inventory, maximize production, and invest in new lower-cost options to include high supersonic missiles. Although current US cruise missiles cost just over $1 million each, this is far less than a hypersonic missile, estimated to cost $30-$50 million each.[137] The US must invest in, develop, and maintain multiple types of cruise missiles, including low observable missiles, upgraded

legacy subsonic missiles, new powered Joint Direct Attack Munitions, and high supersonic missiles. The DoD should continue funding its cruise missile requirements and low-cost alternatives at current levels to achieve the quantity and mix of capabilities needed in a future conflict.

Recommendation 2: Develop the Infrastructure and Supply Chain Needed to Support Emerging Technologies

Issue: The US does not have the DIB necessary to fully support emerging technologies.

A. Infrastructure Investment: HSW testing for the US goes back to the 1940s and 1950s, but test facilities and infrastructure have not received the required attention and upgrades for decades.[138] If Congress and the DoD view HSW technology as a priority, now is the time to fund and upgrade US test facilities, as reflected in the FY23 DoD budget request. The FY22 funding was increased by $800 million, a great start, but appropriators must do more. Upgraded test facilities will not only facilitate the testing of HSW but also allow for the testing of other modernization initiatives.

B. Exotic Material & High-temperature Component Investment: To meet future demands of HSW production, the DoD should invest in exotic materials and high-temperature material manufacturing that will reduce supply chain bottlenecks. The DoD should work with independent companies to modernize the DIB, particularly those working to develop new advanced technology materials.

C. Commercialization Efforts: Another significant factor in the current cost of HSW is the lack of dual-use components. This is especially true for materials needed to shield hypersonic missiles from the extreme heat generated by their flight. There is currently no direct commercial equivalent. However, several companies are considering solutions that may involve affordable

and manufacturable means of controlling "thermos-optical and elastic-optical effects" to reduce the thermal deformation experienced when flying at extreme speeds during commercial space flight.[139] The commercial aviation industry already produces large volumes of highly trusted components and structures, including those which require thermal protection, such as aircraft brakes. Simply having a process to implement improvements in designs and manufacturing techniques enables increased affordability, improved performance, and an increased chance for dual-use manufacturability.[140]

D. Legislative/Executive Branch Efforts: Using congressional authorities to bolster infrastructure and supply chains is essential to maintain the capabilities required in a future conflict. Additional legislation like the CHIPS and Science Act and tapping into the DPA will strengthen US manufacturing and supply chains, encourage workforce growth in STEM fields, and fortify national security. The Legislative and Executive Branches must fully utilize their authorities to advance HSW and DEW development. Moreover, to ensure critical US industries are not subject to supply chain log jams, the government must take steps to either produce its materials or import them from reliable allies and partners.

Recommendation 3: Grow Workforce in Emerging Technologies

Issue: Undermanned engineering and manufacturing workforce to support emerging technology.

A. Invest in STEM / Manufacturing Pipelines: Looking to the future, the government and the DoD must focus on increasing training opportunities for the manufacturing and engineering workforce and providing critical technology protection measures for academia and industry. The pipeline to develop a technical expert in manufacturing and engineering is long, and academia and industry cannot simply create a large pool of experts in one to two years. A strong emphasis must be made on creating more K-12 STEM education opportunities highlighting the variety of

jobs available in the industry. Often, young students look at STEM and assume they must go through a 4-year degree program or longer to enter the industry. STEM education programs must provide awareness of career field opportunities at all levels, including those that need only a high school education, vocational training, or certification program to support the manufacturing workforce. The US must build interest in these careers early to grow the available workforce exponentially and strengthen the DIB.

B. Immigration: While the US remains one of the strongest workforce talent competitors worldwide, there are substantial gaps between the number of workers and the number of open positions. The US must develop innovative programs and incentives to counter the PRC and Russia's advancements and rethink the pathways to highly skilled and high-tech career fields. To retain highly trained foreign students from US technical schools and universities, Congress must consider changes to current immigration laws to account for the demand for high-tech workers. Congress should consider expanded visa categories, increased job portability for visa holders, and expediency and efficiency in green card access.[141]

C. Diversity and Inclusion Initiatives: The US must also continue to prioritize and leverage underrepresented racial and gender groups to increase its workforce population in emerging technologies. Supporting and incentivizing programs that leverage the best talent is vital to US interests as it continues to compete with the PRC and Russia.

Recommendation 4: Leverage Allies and Partners

Issue: The US does not have the workforce and infrastructure needed to outcompete the PRC.

A. Joint Research, Development, & Testing: Partnerships such as AUKUS provide a template for collaboration and technology sharing. The AUKUS agreement includes nuclear-powered submarines, quantum technology, hypersonic capabilities, and artificial intelligence.[142] The goal

of this partnership is a global deterrence effort, and the US should seek more AUKUS-like agreements in the Indo-Pacific region and Europe, with countries like South Korea and France.[143] South Korea has become a significant player in semiconductor chips, making them a logical partner to deter the PRC from taking aggressive actions in the region. The France-UK relationship has become fractured, but a potential trilateral agreement with the US may assist in mending this key European relationship and support a stable and secure Europe.[144]

B. Cost-Sharing Measures: Encouraging cooperation and partnerships among stakeholders through joint research projects, cooperative agreements, and technology sharing can significantly advance the HSW and DEW industries. Pooling resources and sharing expertise enables stakeholders to overcome challenges, address concerns, reduce costs, and accelerate the development of advanced weapons systems. These collaborative efforts can be vital to solving complex technical and other issues and achieving common goals in these areas, ensuring a more efficient and sustainable development process for all parties involved in these advanced technologies.

C. Diplomatic & Transparency Efforts: To enhance diplomatic relationships between the US and the international community, the US should advocate for an amendment to the Wassenaar Arrangement. The Wassenaar Arrangement, a voluntary export control regime, includes 42 countries that share information regarding the transfer of conventional weapons and dual-use technologies to countries that are not a part of the agreement.[145] The US should advocate for including details on transferring hypersonic technology, components, and weapons to non-state actors. This level of transparency will ensure international stability, transparency, and accountability for transferring weapons and technology to other nations.

CONCLUSION

The 2022 NSS and NDS designate the PRC as the pacing threat and Russia as an enduring acute threat.[146,147] These strategic documents provide a roadmap for the US to counter, outcompete, deter, and if necessary, defeat the PRC and Russia. As these adversaries attempt to exert their influence across the globe, they have invested in advanced weaponry, including HSW and DEW, which have given them an asymmetric advantage over the US. More specifically, when looking through the lens of the PRC's potential conflict with Taiwan, the PRC is using HSW and DEW to extend its A2/AD capabilities. In doing so, the PRC's strategy is to push the US further from the area of conflict to limit the US responsiveness and impact. As this paper argued, to deter the PRC from attempting to reshape the liberal world order, the US should continue to develop HSW and DEW for offensive and defensive capabilities to complement its current arsenal while addressing DIB issues, including infrastructure, supply chain, and human capital, and fostering cooperation with allies and partners.

The development of HSW and DEW is not without its challenges, however. The DIB lacks the number of firms that research, develop, and produce HSW and DEW, the requisite supply chains that provide the necessary raw materials and components, and the infrastructure required to adequately test these weapons. The decline in the workforce and the continued lack of diversity and inclusion across the industry impede the ability to meet current requirements and stifle innovation. Collectively, these issues have exacerbated the development and fielding of HSW and DEW and are partially responsible for the current high production costs.

The above challenges are significant but not insurmountable. This report provided recommendations to develop specific requirements for HSW and DEW to deliver a consistent demand signal to the industry on the current and future production needs and better inform

requirements for other weapons systems. Focusing on securing supply chain and infrastructure shortfalls while addressing systemic human capital issues will significantly improve the DIB. Working with partners and allies across all these areas will lower the current cost to produce HSW and DEW and better define the collective development requirements. The government must work with industry and academia to address and incorporate these recommendations. If the above issues are not addressed, the PRC will be allowed to maintain and grow its asymmetric advantage and potentially dictate what happens next.

Finally, there are still some unanswered questions, including legal and ethical, surrounding the development, production, and implementation of HSW and DEW, which undoubtedly reside in the classified world, and hence were not included in this report. Several articles referenced in this report posed questions about the potential future commercialization of DEW and HSW. DEW appears to have relevant commercial security applications for large public gatherings, but questions remain about where the authorities to use DEW commercially would be granted and how to regulate them. Additionally, several articles called for research into the applicability of commercial flight at hypersonic speeds, specifically asking if larger aircraft traveling at hypersonic speeds would experience the same atmospheric effects and, if so, how to mitigate them. The more these technologies can be commercialized, the more likely cost savings will be realized for HSW and DEW manufacturing and production.

There is also much debate regarding the potential integration of HSW and DEW with artificial intelligence and autonomous machines. Given the atmospheric effects HSW can experience, which can degrade communications, there is a potential for autonomy to guide these weapons to their final targets. Finally, questions remain regarding the potential overlap between offensive HSW development and the US defensive measures. Developments made in offensive

HSW capabilities should be shared with the MDA as they develop defensive capabilities, including the potential integration of DEW. As further research into these and other questions is conducted, the potential for additional HSW and DEW military and commercial applications could arise.

APPENDICES

Appendix A:

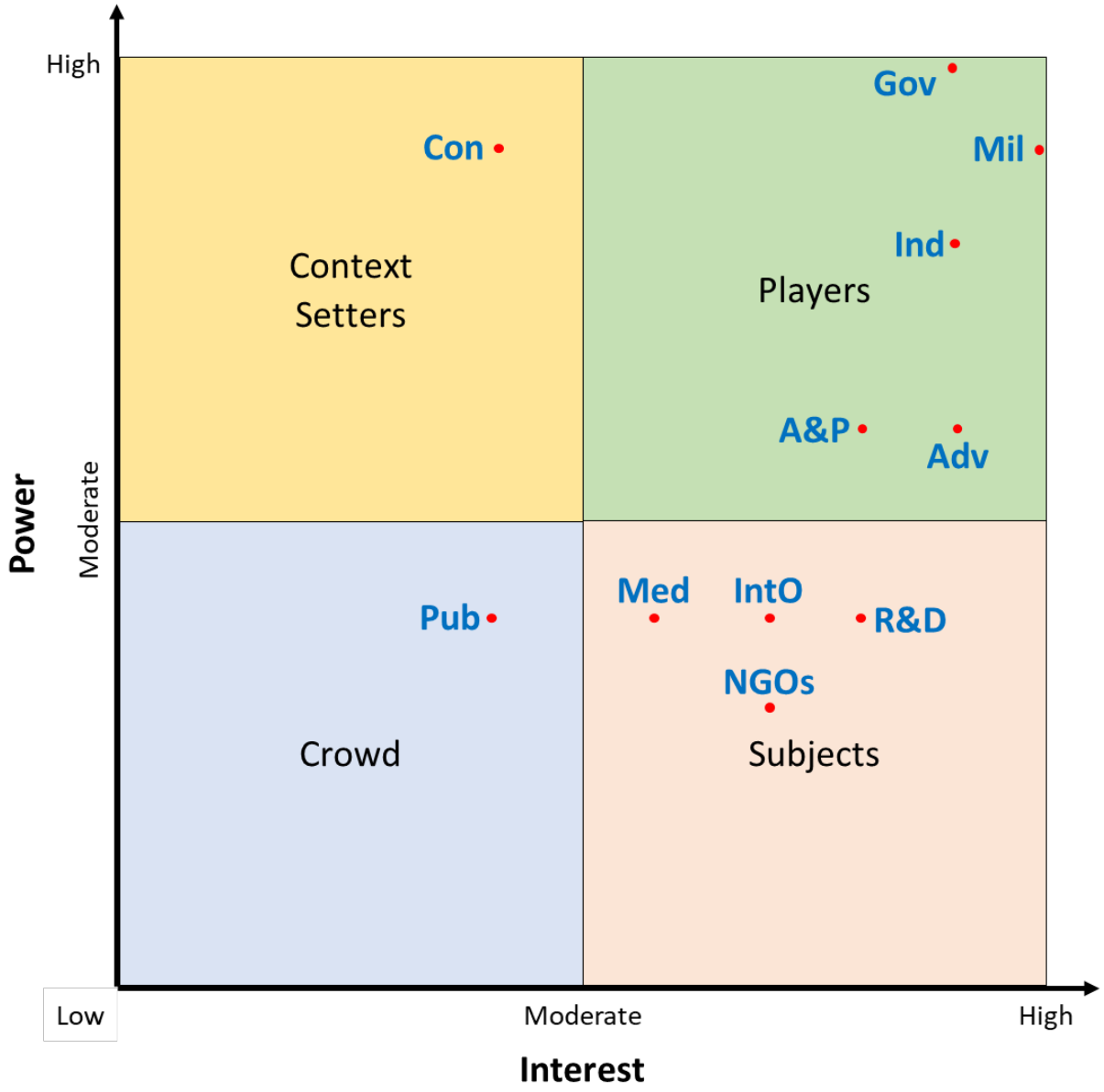
The comprehensive list of stakeholders and sub-stakeholders*

The US Government	Military services
– President of the United States – Congress – Supreme Court of the United States – Department of Defense (DoD) – Department of State (DoS) – Department of Energy (DoE) – Department of Commerce – Defense Advanced Research Projects Agency (DARPA)	– United States Air Force – United States Army – United States Navy – United States Marine Corps – United States Space Force
Defense contractors and industry partners	**Allies and partners**
– Major defense companies (e.g., Lockheed Martin, Raytheon Technologies, Boeing, Northrop Grumman, etc.) – Small and medium-sized enterprises (SMEs) (e.g., Dynetics, Epirus, Aerojet Rocketdyne, etc.) – Subcontractors and suppliers	– NATO and its member countries – European Union – Major non-NATO allies (e.g., Japan, South Korea, Australia, Israel, etc.) – Bilateral defense cooperation partners
Potential adversaries	**Academia and research institutions**
– Potential adversaries' governments – Potential adversaries' armed forces – Potential adversaries' research institutions	– Universities – Research and Development Centers – Think Tanks (e.g., RAND Corporation, Center for Strategic and International Studies) –
International organizations	**Non-governmental organizations**
– United Nations – Organization for Security and Co-operation in Europe (OSCE) – International Atomic Energy Agency	– Human rights organizations (e.g., Amnesty International, Human Rights Watch) – Environmental organizations (e.g., Greenpeace, Sierra Club) – Arms control and disarmament organizations (e.g., Arms Control Association) –
Media	**Public**
– Print media – Broadcast media – Online media	– Individual citizens – Local communities – Workers in the industry

* The list of stakeholders and sub-stakeholders in hypersonic and directed energy weapons industries is not exhaustive and is subject to change as new entities emerge and existing ones evolve. Some entities can belong to multiple categories based on their roles and interests.

Appendix B:

Power/Interest Grid with Stakeholders

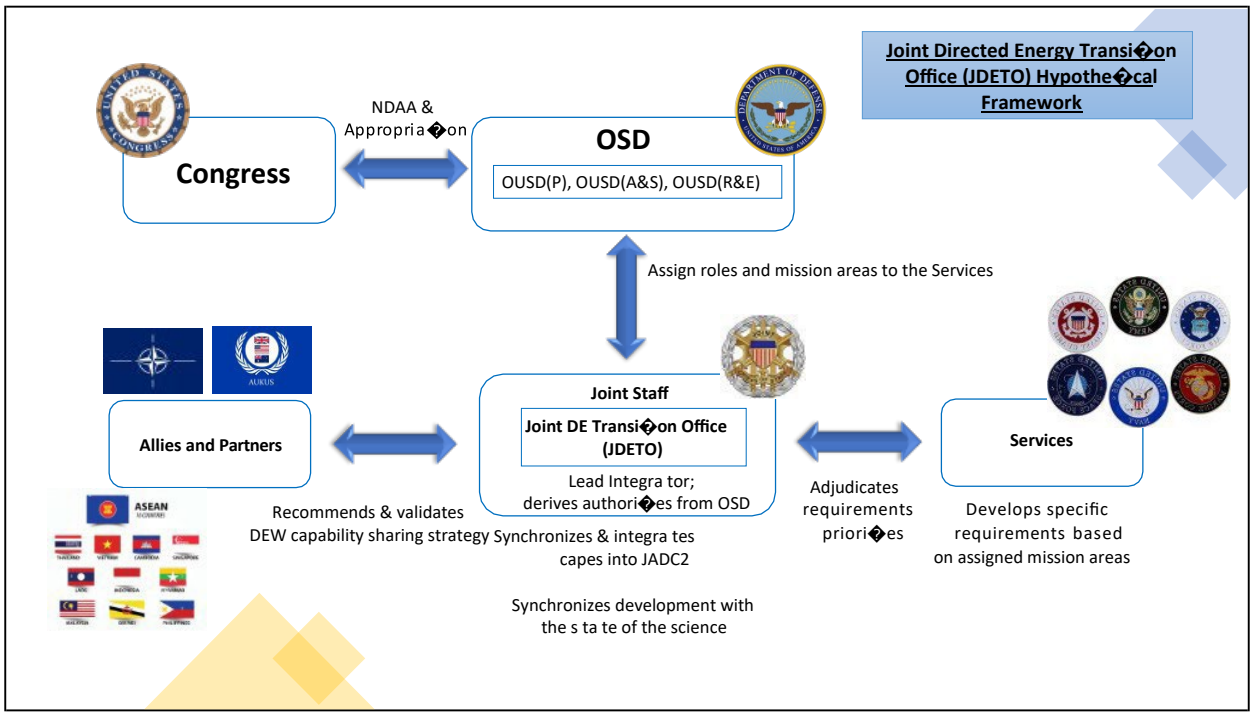


Legend:

Gov – The US Government
Mil – Military services
Ind – Defense contractors and industry partners
A&P – Allies and partners
IntO – International organizations
R&D – Academia and research institutions
Adv – Potential adversaries
Pub – Public
Med – Media
NGOs – Non-governmental organizations
Con – Congress

Appendix C:

Joint Directed Energy Transition Office (JDETO) Hypothetical Framework



Appendix D:

Glossary of Acronyms

A2/AD	Anti-Access Area Denial
ACE	America's Cutting Edge
ARRW	Air-launched Rapid Response Weapon
AUKUS	Australia, United Kingdom, United States
C2	Command and Control
C-RAM	Counter-Rocket, Artillery and Mortar
C-UAS	Counter Unmanned Aircraft Systems
CBO	Congressional Budget Office
CHIPS	Creating Helpful Incentives to Produce Semiconductors
DARPA	Defense Advanced Research Projects Agency
DEW	Directed Energy Weapons
DIB	Defense Industrial Base
DoD	Department of Defense
GDP	Gross Domestic Product
GPI	Glide Phase Interceptor
HACM	Hypersonic Attack Cruise Missile
HALO	Hypersonic Air-Launched Offensive
HAWC	Hypersonic Air-breathing Weapon Concept
HCM	Hypersonic Cruise Missile
HEL	High Energy Laser
HGV	Hypersonic Glide Vehicle
HPM	High Powered Microwave
HSW	Hypersonic Weapon
ICBM	Intercontinental Ballistic Missile
IR-CPS	Intermediate-range Conventional Prompt Strike
JDETO	Joint Directed Energy Weapon Transition Office
LRHW	Long Range Hypersonic Weapon
MDA	Missile Defense Agency

NATO	North Atlantic Treaty Organization
NDS	National Defense Strategy
NEW	Nontraditional Employment for Women
NGO	Non-Governmental Organization
NSS	National Security Strategy
PLA	People's Liberation Army
PRC	People's Republic of China
R&D	Research and Development
SCP	Structure, Conduct, Performance
SCS	South China Sea
SHORAD	Short-Range Air Defense
STEM	Science, Technology, Engineering and Math
TBG	Tactical Boost Glide
UCAH	University Consortium for Applied Hypersonics

NOTES

[1] Joseph Biden, *National Security Strategy*, (Washington, DC: The White House, October 2022), 22.

[2] Anthony Capaccio, "China Has Lead Over Russia In Hypersonic Weapons, DIA Says," Bloomberg, March 10, 2023, https://www.bloomberg.com/news/articles/2023-03-10/dia-says-china-has-lead-over-russia-in-hypersonic-weapons?leadSource=uverify%20wall.

[3] Jeffrey Taylor, "Contextualizing Russia's Hypersonic Threat: Perceptions, Motivations, and Strategic Stability," *Space & Defense* 13, no. 1 (July 1, 2022): 31.

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