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Department of Defense Directed Energy Weapons: Background and Issues for Congress

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Department of Defense Directed Energy Weapons: Background and Issues for Congress

SUMMARY

Directed energy (DE) weapons use concentrated electromagnetic energy, rather than kinetic energy, to combat enemy forces. Although the United States has been researching directed energy since the 1960s, some experts have observed that the Department of Defense (DOD) has invested billions of dollars in DE programs that failed to reach maturity and were ultimately cancelled. In recent years, however, DOD has made progress on DE weapons development, deploying the first operational U.S. DE weapon in 2014 aboard the USS *Ponce*. Since then, DE weapons development has continued, with DOD issuing a Directed Energy Roadmap to coordinate the department's efforts. DOD has also introduced a High Energy Laser Scaling Initiative, which seeks to strengthen the defense industrial base for DE weapons and improve laser beam quality and efficiency.

This report provides background information and issues for Congress on DE weapons, including high-energy lasers (HELs) and high-powered microwave (HPM) weapons, and outlines selected unclassified DOD, Air Force, Army, and Navy DE programs. If successfully fielded, HELs could be used by ground forces in a range of missions, including short-range air defense (SHORAD); counter-unmanned aircraft systems (C-UAS); and counter-rocket, artillery, and mortar (C-RAM) missions. HPM weapons could provide a nonkinetic means of disabling adversary electronics and communications systems. Compared with traditional munitions, DE weapons could offer lower logistical requirements, lower costs per shot, and—assuming access to a sufficient power supply—deeper magazines. These weapons could, however, face limitations not faced by their kinetic counterparts. For example, atmospheric conditions (e.g., rain, fog, obscurants) could potentially limit the range and beam quality of DE weapons, in turn reducing their effectiveness.

As DOD continues to invest in DE weapons, Congress may consider the weapons' technological maturity, lifecycle cost, characteristics, mission utility, industrial base, intelligence requirements, and oversight structure. Congress may also consider the implications of DE weapons for future arms control agreements.

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Introduction

This report provides background information and issues for Congress on Department of Defense (DOD) efforts to develop and procure directed energy (DE) weapons. The report provides an overview of certain DOD, Air Force, Army, and Navy DE programs. Two other CRS reports provide additional discussion of Army and Navy DE programs.[1] Some types of DE weapons, such as particle-beam weapons, are outside the scope of this report.

DOD's efforts on DE weapons pose a number of potential issues for Congress. Decisions that Congress makes on these issues could have substantial implications for future DOD capabilities and funding requirements and the U.S. defense industrial base.

Overview of Directed Energy Weapons[2]

DOD defines directed energy weapons as those using concentrated electromagnetic energy, rather than kinetic energy, to "incapacitate, damage, disable, or destroy enemy equipment, facilities, and/or personnel."[3] DE weapons include high-energy laser (HEL) and high-powered microwave (HPM) weapons.

HEL weapons might be used by ground forces in various missions, including short-range air defense (SHORAD); counter-unmanned aircraft systems (C-UAS); and counter-rocket, artillery, and mortar (C-RAM) missions.[4] The weapons might be used to "dazzle" (i.e., temporarily disable) or damage satellites and sensors. This could in turn interfere with intelligence-gathering operations; military communications; and positioning, navigation, and timing systems used for weapons targeting. In addition, HEL weapons could theoretically provide options for boost-phase missile intercept, given their speed-of-light travel time; however, experts disagree on the affordability, technological feasibility, and utility of this application.[5]

In general, HEL weapons might offer lower logistical requirements, lower costs per shot, and—assuming access to a sufficient power supply—deeper magazines compared with traditional munitions. (Although a number of different types of HELs exist, many of the United States' current programs are solid state lasers, which are fueled by electrical power. As a result, the cost per shot would be equivalent to the cost of the electrical power required to fire the shot.)[6] These

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[1] See CRS Report R45098, *U.S. Army Weapons-Related Directed Energy (DE) Programs: Background and Potential Issues for Congress*, by Andrew Feickert, and CRS Report R44175, *Navy Shipboard Lasers: Background and Issues for Congress*, by Ronald O'Rourke.

[2] This section was written by Kelley M. Sayler, CRS Specialist in Advanced Technology and Global Security. For more information—including information about DE weapons programs in China and Russia—see CRS Report R46458, *Emerging Military Technologies: Background and Issues for Congress*, by Kelley M. Sayler.

[3] Joint Chiefs of Staff, *Joint Electromagnetic Spectrum Operations, Joint Publication 3-85*, May 22, 2020, p. GL-6.

[4] For more information about the role of DE weapons in C-UAS missions, see CRS In Focus IF11426, *Department of Defense Counter-Unmanned Aircraft Systems*, by John R. Hoehn and Kelley M. Sayler.

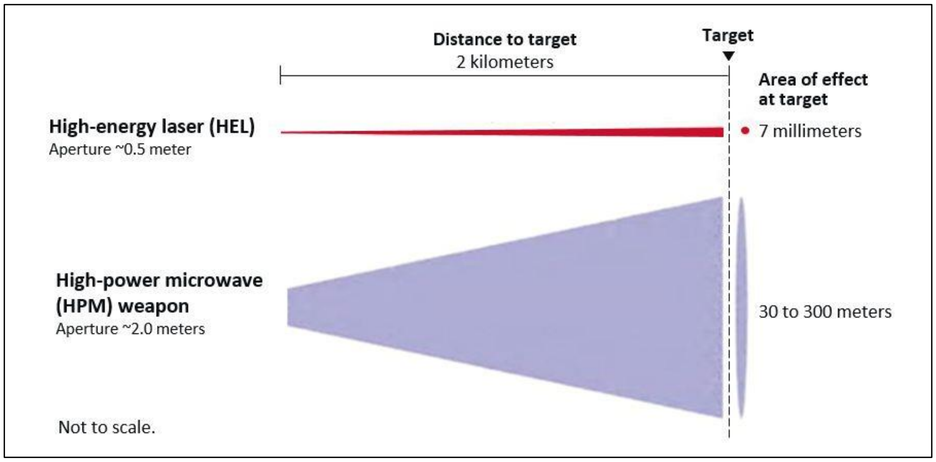
[5] See, for example, James N. Miller and Frank A. Rose, "Bad Idea: Space-Based Interceptors and Space-Based Directed Energy Systems," Center for Strategic and International Studies, December 13, 2018, at https://defense360.csis.org/bad-idea-space-based-interceptors-and-space-based-directed energy-systems/; and Justin Doubleday, "Pentagon punts MDA's laser ambitions, shifts funding toward OSD-led 'laser scaling,'" *Inside Defense*, February 19, 2020, at https://insidedefense.com/daily-news/pentagon-punts-mdas-laser-ambitions-shifts-funding-toward-osd-led-laser-scaling.

[6] Ariel Robinson, "Directed Energy Weapons: Will They Ever Be Ready?," *National Defense*, July 1, 2015, at https://www.nationaldefensemagazine.org/articles/2015/7/1/2015july-directed energy-weapons-will-they-ever-be-ready.

characteristics could in turn produce a favorable cost-exchange ratio for a defender, whose marginal costs would be significantly lower than those of an aggressor.

Similarly, HPM weapons could provide a nonkinetic means of disabling adversary electronics and communications systems. These weapons could potentially generate effects over wider areas—disabling any electronics within their electromagnetic cone—than HEL weapons, which emit a narrower beam of energy (see **Figure 1**). Some analysts have noted that HPM weapons might provide more effective area defense against missile salvos and swarms of unmanned aircraft systems. HPM weapons in an anti-personnel configuration might provide a means of nonlethal crowd control, perimeter defense, or patrol or convoy protection.[7] Potential advantages and limitations of both HEL and HPM weapons are discussed in greater detail in **Appendix A**.

Figure 1. Illustrative Effects of HELs Versus HPM Weapons



Source: CRS image based on an image in Mark Gunzinger and Chris Dougherty, *Changing the Game: The Promise of Directed-Energy Weapons*, Center for Strategic and Budgetary Assessments, April 19, 2021, p. 40, at https://csbaonline.org/uploads/documents/CSBA_ChangingTheGame_ereader.pdf.

Note: Units of measurement are illustrative.

Selected Defense-Wide Directed Energy Programs[8]

DOD directed energy programs are coordinated by the Principal Director for Directed Energy within the Office of the Under Secretary of Defense for Research and Engineering (OUSD[R&E]). The Principal Director for Directed Energy is responsible for development and oversight of the Directed Energy Roadmap, which articulates DOD's objective of "[achieving] dominance in DE military applications in every mission and domain where they give advantage."[9] According to OUSD(R&E), the current roadmap outlines DOD's plans to increase power levels of HEL weapons from around 150 kilowatt (kW), as is currently feasible, to around 300 kW by FY2023, "with goal milestones to achieve 500 kW class with reduced size and weight by FY2025 and to further reduce size and weight and increase power to MW [megawatt] levels by

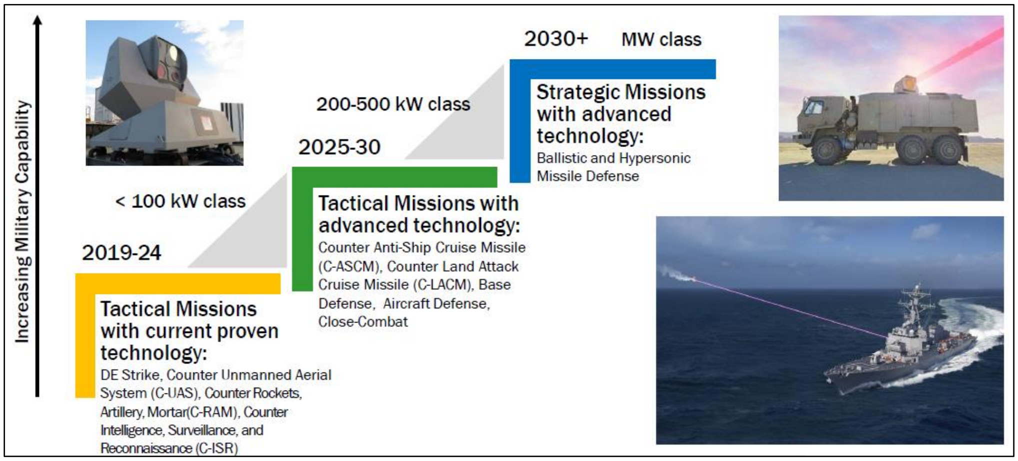
[7] See, for example, Joint Intermediate Force Capabilities Office, "Active Denial System FAQs," https://jnlwp.defense.gov/About/Frequently-Asked-Questions/Active-Denial-System-FAQs/.

[8] This section was written by Kelley M. Sayler, CRS Analyst in Advanced Technology and Global Security.

[9] Dr. Jim Trebes, "Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?," presentation at the Institute for Defense and Government Advancement (IDGA), October 21, 2020.

FY2026."[10] For reference, although no consensus exists regarding the precise power level that would be needed to neutralize different target sets, DOD briefing documents (see **Figure 2**) suggest that a laser of approximately 100 kW could engage UASs, rockets, artillery, and mortars, whereas a laser of around 300 kW could additionally engage small boats and cruise missiles flying in certain profiles (i.e., flying across—rather than at—the laser).[11] Lasers of 1 MW could potentially neutralize ballistic missiles and hypersonic weapons.[12]

Figure 2. Summary of DOD Directed Energy Roadmap



Source: Dr. Jim Trebes, "Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?," presentation at the Institute for Defense and Government Advancement (IDGA), October 21, 2020.

In addition to managing the DE roadmap, OUSD(R&E) manages the High Energy Laser Scaling Initiative (HELSI), which seeks "to demonstrate laser output power scaling while maintaining or improving beam quality and efficiency."[13] HELSI is intended to strengthen the defense industrial base for potential future DE weapons by providing near-term prototyping opportunities for industry partners.[14] OUSD(R&E) has completed a DOD-wide Laser Lethality Analysis Process Review to identify future needs for the department and best practices for DE development and use. In addition, OUSD(R&E) is developing a Directed Energy Lethality Database, a searchable repository for DOD's DE analyses.[15]

[10] CRS correspondence with the Office of the Under Secretary of Defense for Research and Engineering, September 8, 2022. Kilowatts and megawatts are units of power. For example, 1 kilowatt is equal to 1,000 watts, and 1 megawatt is equal to 1 million watts.

[11] Dr. Jim Trebes, "Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?," presentation at IDGA, October 21, 2020; and CRS conversation with Principal Director for Directed Energy Modernization Dr. Jim Trebes, November 17, 2020. Required power levels could be affected by additional factors such as adversary countermeasures and atmospheric conditions and effects.

[12] Dr. Jim Trebes, "Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?," presentation at IDGA, October 21, 2020.

[13] Dr. Jim Trebes, "Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?," presentation at IDGA, October 21, 2020.

[14] Industry participants in HELSI include nLight-Nutronics (sponsored by the Navy), Lockheed Martin (sponsored by the Army), General Atomics (sponsored by the Air Force), and Northrop Grumman. Nancy Jones-Bonbrest, "Scaling Up: Army Advances 300kW-class Laser Prototype," Army Rapid Capabilities and Critical Technologies Office, March 3, 2020, at https://www.army.mil/article/233346/scaling_up_army_advances_300kw_class_laser_prototype; and CRS conversation with Principal Director for Directed Energy Dr. Frank Peterkin, May 17, 2023.

[15] The database has been populated with limited data and is being updated based on user feedback. OUSD(R&E) plans (continued...)

In support of these initiatives, DOD maintains a number of research programs, including programs at the Missile Defense Agency (MDA), the Office of the Secretary of Defense (OSD), and the Defense Advanced Projects Research Agency (DARPA). For example, MDA's Directed Energy Demonstrator Development program addresses "technology risk reduction and maturation for high powered strategic lasers, beam control, lethality, and related technologies" in support of OUSD(R&E)'s Directed Energy Roadmap.[16] The program received $42 million in FY2021. Although MDA did not request funding for the program in FY2022 or FY2023 "due to a shift in Department of Defense priorities," Congress appropriated $39 million and $16 million, respectively, to continue development efforts.[17] MDA did not request funds for the Directed Energy Demonstrator Development program in FY2024.[18]

In FY2024, OSD requested $16 million for High Energy Laser Research Initiatives, including basic research and educational grants, and $49 million for High Energy Laser Development, which funds applied research.[19] OSD additionally requested $112 million in FY2024 for High Energy Laser Advanced Development, which is focused on "scaling the output power of DE systems to reach operationally effective power levels applicable to broad mission areas across the DOD."[20] OSD requested $10 million in FY2024 to continue assessments of directed energy weapons, including assessments of the weapons' effects, effectiveness, and limitations.[21] Finally, DARPA's Waveform Agile Radio-frequency Directed Energy (WARDEN) program seeks to "extend the range and lethality of high power microwave weapons ... [for] counter-unmanned aerial systems, vehicle and vessel disruption, electronic strike, and guided missile defense."[22]

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to have an updated version of the database available in FY2023. CRS correspondence with Distinguished Scientist for Laser Weapon Systems Lethality Dr. Christopher Lloyd, August 29, 2022.

[16] DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5 Research, Development, Test & Evaluation, Defense-Wide*, pp. 601-603, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol2_MDA_RDTE_PB23_Justification_Book.pdf.

[17] DOD, *Department of Defense Fiscal Year (FY) 2024 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5 Research, Development, Test & Evaluation, Defense-Wide*, pp. 605, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2024/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol2_MDA_RDTE_PB24_Justification_Book.pdf.

[18] DOD, *Department of Defense Fiscal Year (FY) 2024 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5 Research, Development, Test & Evaluation, Defense-Wide*, pp. 605, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2024/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol2_MDA_RDTE_PB24_Justification_Book.pdf.

[19] DOD, *Department of Defense Fiscal Year (FY) 2024 Budget Estimates, Office of the Secretary of Defense, Defense-Wide Justification Book Volume 3 of 5 Research, Development, Test & Evaluation*, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2024/budget_justification/pdfs/03_RDT_and_E/OSD_PB2024.pdf. These programs were transferred to OSD from the Air Force to "better align [the] research area to Department of Defense Science and Technology strategy and priorities for Directed Energy." This transfer could reflect greater coordination across DOD DE programs. DOD, *Department of Defense Fiscal Year (FY) 2022 Budget Estimates, Office of the Secretary of Defense, Defense-Wide Justification Book Volume 3 of 5 Research, Development, Test & Evaluation*, pp. 1 and 79, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2022/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol3_OSD_RDTE_PB22_Justification_Book.pdf.

[20] DOD, *Department of Defense Fiscal Year (FY) 2024 Budget Estimates, Office of the Secretary of Defense, Defense-Wide Justification Book Volume 3 of 5 Research, Development, Test & Evaluation*, p. 371, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2024/budget_justification/pdfs/03_RDT_and_E/OSD_PB2024.pdf.

[21] DOD, *Department of Defense Fiscal Year (FY) 2024 Budget Estimates, Office of the Secretary of Defense, Defense-Wide Justification Book Volume 3 of 5 Research, Development, Test & Evaluation*, p. 393, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2024/budget_justification/pdfs/03_RDT_and_E/OSD_PB2024.pdf.

[22] DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Defense Advanced Research Projects* (continued...)

DARPA received $20 million for WARDEN in FY2023 and requested $20 million for the program in FY2024.[23]

Overall, DOD requested approximately $1 billion for directed energy weapons programs in FY2024.[24]

Selected Air Force Directed Energy Weapons Programs[25]

The Air Force is developing and testing a number of DE technologies through the Directed Energy Directorate of the Air Force Research Laboratory (AFRL). The following section provides a brief description of selected unclassified efforts.

Tactical High-Power Operational Responder (THOR)

The Tactical High-Power Microwave Operational Responder (THOR) technology demonstrator (see **Figure 3**), designed by AFRL in collaboration with industry partners, is intended to provide a viable DE C-UAS weapon system focused on short-range air base defense.[26] THOR is housed in a standardized 20-foot transport container that enables it to fit inside a C-130 transport aircraft. Users reportedly can deploy the system in three hours and operate its user interface with only rudimentary training.[27] According to Air Force press releases, THOR has successfully completed a two-year test period and is to inform follow-on prototype efforts such as Mjölnir.[28]

Agency, Defense-Wide Justification Book Volume 1 of 5 Research, Development, Test & Evaluation, p. 145, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol1_DARPA_MasterJustificationBook_PB_2023.pdf.

[23] DOD, *Department of Defense Fiscal Year (FY) 2024 Budget Estimates, Defense Advanced Research Projects Agency, Defense-Wide Justification Book Volume 1 of 5 Research, Development, Test & Evaluation*, p. 140, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2024/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol1_DARPA_MasterJustificationBook_PB_2024.pdf.

[24] CRS conversation with Principal Director for Directed Energy Dr. Frank Peterkin, May 17, 2023. See also Government Accountability Office, *Directed Energy Weapons: DOD Should Focus Transition on Planning*, April 2023, p. 1.

[25] This section was written by former CRS Research Assistant Samuel D. Ryder and former CRS Analyst in Military Capabilities and Programs John R. Hoehn.

[26] Industry partners include BAE Systems, Leidos, and Verus Research. THOR also features a proprietary radar system developed by Black Sage.

[27] Bryan Ripple, "Enemy drone operators may soon face the power of THOR," 88th Air Base Wing Public Affairs, September 24, 2019, at https://www.af.mil/News/Article-Display/Article/1836495/air-force-research-laboratory-completes-successful-shoot-down-of-air-launched-m/.

[28] 1st Lt. James Wymer, "AFRL's drone killer, THOR will welcome new drone 'hammer,'" *U.S. Air Force*, August 2, 2021, at https://www.af.mil/News/Article-Display/Article/2713908/afrls-drone-killer-thor-will-welcome-new-drone-hammer/.

Figure 3. THOR Demonstrator

Source: U.S. Air Force, AFRL Directed Energy Directorate, press release, September 24, 2019.

Phaser High-Powered Microwave

The Phaser High-Powered Microwave system (see **Figure 4**), developed by Raytheon, is intended to provide a short-range C-UAS capability similar to that of THOR. The Air Force reportedly procured a $16.3 million prototype Phaser for testing and overseas field assessments; however, it is unclear whether the system has been deployed outside the United States.[29]

Figure 4. Phaser Demonstrator

Source: Raytheon Missiles and Defense, Phaser product page, February 2020.

Counter-Electronic High-Power Microwave Extended-Range Air Base Defense (CHIMERA)

AFRL awarded Raytheon Missiles and Defense a contract for testing of the Counter-Electronic High-Power Microwave Extended-Range Air Base Defense (CHIMERA) system in October 2020. In contrast to THOR and Phaser, which are designed for a short-range C-UAS mission, the

[29] Joe Pappalardo, "The Air Force Is Deploying Its First Drone-Killing Microwave Weapon," *Popular Mechanics*, September 24, 2019, at https://www.popularmechanics.com/military/weapons/a29198555/phaser-weapon-air-force/; and Theresa Hitchens, "AF Says Lasers Are Being Field Tested, but NOT THOR or Other Microwave Weapons," *Breaking Defense*, December 22, 2020, at https://breakingdefense.com/2020/12/af-says-lasers-are-being-field-tested-but-not-thor-or-other-microwave-weapon/.

CHIMERA system is intended to be able to engage UAS at greater distances.[30] Unclassified information about the CHIMERA system is limited.

High-Energy Laser Weapon System (HELWS)

The High-Energy Laser Weapon System (HELWS) is to serve as a mobile C-UAS capability for air base defense (see **Figure 5**). The system comprises a laser weapon and multispectral targeting system mounted on the back of a Polaris MRZR all-terrain vehicle and can reportedly operate at distances of up to 3 km.[31] HELWS developer Raytheon claims the laser can fire dozens of shots using a single charge from a standard 220-volt outlet, and an indefinite number of shots if connected to an external power source such as a generator.[32] The Air Force acquired the first HELWS in October 2019 and reportedly deployed HELWS overseas for field assessments in April 2020.[33] The Air Force awarded Raytheon a $15.5 million contract for an upgraded version of HELWS in April 2021.[34] This version is to be "delivered unmounted on pallets for potential use with different platforms."[35]

Figure 5. HELWS Prototype

Source: Raytheon Missiles and Defense, HELWS product page, April 2020.

[30] Sara Sirota, "AFRL to award Raytheon sole-sourced contract for directed energy weapon," *Inside Defense*, October 29, 2020, at https://insidedefense.com/insider/afrl-award-raytheon-sole-sourced-contract-directed-energy-weapon.

[31] Raytheon, "Raytheon Intelligence & Space delivers another Air Force laser system ready for operational use," September 14, 2020, https://www.raytheonintelligenceandspace.com/news/advisories/raytheon-intelligence-space-delivers-another-air-force-laser-system-ready; and Nathan Strout, "Raytheon awarded $15.5 million to upgrade laser weapon," *C4ISRNET*, April 7, 2021, at https://www.c4isrnet.com/unmanned/2021/04/07/raytheon-awarded-155-to-upgrade-laser-weapon/.

[32] Kyle Mizokami, "The Air Force Mobilizes Its Laser and Microwave Weapons Abroad," *Popular Mechanics*, April 9, 2020, at https://www.popularmechanics.com/military/weapons/a32083799/laser-microwave-weapons/; and Raytheon, "Raytheon Intelligence & Space delivers another Air Force laser system ready for operational use," September 14, 2020, at https://www.raytheonintelligenceandspace.com/news/advisories/raytheon-intelligence-space-delivers-another-air-force-laser-system-ready.

[33] Raytheon, "Raytheon Delivers First Laser Counter-UAS System to U.S. Air Force," October 22, 2019, at https://raytheon.mediaroom.com/2019-10-22-Raytheon-delivers-first-laser-counter-UAS-System-to-U-S-Air-Force#:~:text=Laser%20dune%20buggy%20set%20for,Air%20Force%20earlier%20this%20month; and 88th Air Base Wing Public Affairs, "AFRL gives warfighters new weapons system," April 6, 2020, at https://www.whs.mil/News/News-Display/Article/2138161/afrl-gives-warfighters-new-weapons-system/.

[34] Nathan Strout, "Raytheon awarded $15.5 million to upgrade laser weapon," *C4ISRNET*, April 7, 2021, at https://www.c4isrnet.com/unmanned/2021/04/07/raytheon-awarded-155-to-upgrade-laser-weapon/.

[35] Ibid.

Self-Protect High-Energy Laser Demonstrator (SHiELD)

The Self-Protect High-Energy Laser Demonstrator (SHiELD) is a prototype system in development by AFRL, Boeing, Lockheed Martin, and Northrop Grumman (see **Figure 6**). It is intended to mount as an external pod on Air Force aircraft—from fourth-generation F-15 fighters to sixth-generation aircraft currently in development—and target incoming air-to-air and surface-to-air missiles.[36] The Air Force conducted a series of tests of the Demonstrator Laser Weapon System, a ground-based test surrogate for SHiELD, in April 2019. The demonstrator successfully engaged incoming missiles and helped validate SHiELD's technology; however, technical issues and challenges related to the COVID-19 pandemic have reportedly pushed SHiELD's first flight demonstration from FY2021 to FY2024.[37] Furthermore, at a June 2020 Mitchell Institute event, then-Assistant Secretary of the Air Force Will Roper stated that the Air Force is reassessing the technological maturity of and use cases for SHiELD, as well as its potential role in missile defense missions.[38] Former Under Secretary of Defense for Research and Engineering Mike Griffin has noted that he is "extremely skeptical that we can put a large laser on an aircraft and use it to shoot down an adversary missile, even from fairly close."[39]

Figure 6. SHiELD Prototype Rendering

Source: Lockheed Martin, Tactical Airborne Laser Weapon System, September 14, 2020.

[36] See Joanne Perkins, "AFRL's SHiELD set to receive critical assembly," *Air Force Research Laboratory*, February 23, 2021, at https://www.afrl.af.mil/News/Article-Display/Article/2511692/afrls-shield-set-to-receive-critical-assembly/.

[37] "Air Force Research Laboratory completes successful shoot down of air-launched missiles," 88th Air Base Wing Public Affairs, May 3, 2019, at https://www.af.mil/News/Article-Display/Article/1836495/air-force-research-laboratory-completes-successful-shoot-down-of-air-launched-m/; Valerie Insinna, "US Air Force delays timeline for testing a laser on a fighter jet," *Defense News*, June 30, 2020, at https://www.defensenews.com/air/2020/06/30/us-air-force-delays-timeline-for-testing-a-laser-on-a-fighter-jet/; and Nathan Strout, "Air Force to begin assembly of airborne laser," *C4ISRNET*, February 23, 2021, at https://www.c4isrnet.com/battlefield-tech/2021/02/23/air-force-to-begin-assembly-of-airborne-laser/.

[38] Valerie Insinna, "US Air Force delays timeline for testing a laser on a fighter jet," *Defense News*, June 30, 2020, at https://www.defensenews.com/air/2020/06/30/us-air-force-delays-timeline-for-testing-a-laser-on-a-fighter-jet/.

[39] Aaron Mehta, "Griffin 'extremely skeptical' of airborne lasers for missile defense," *Defense News*, May 20, 2020, at https://www.defensenews.com/2020/05/20/griffin-extremely-skeptical-of-airborne-lasers-for-missile-defense/.

Selected Army Directed Energy Weapons Programs[40]

The Army Rapid Capabilities and Critical Technologies Office (RCCTO) is currently managing three major Army DE weapons programs:

- Directed Energy Maneuver-Short Range Air Defense (DE M-SHORAD),
- Indirect Fire Protection Capability-High Energy Laser (IFPC-HEL), and
- Indirect Fire Protection Capability-High Power Microwave (IFPC-HPM).[41]

The Army is developing DE weapons to counter UAS and rockets, artillery, and mortars (RAM), in turn increasing Army air and missile defense capability and reducing total system lifecycle costs by means of reduced logistical demands.[42]

Directed Energy Maneuver-Short-Range Air Defense (DE M-SHORAD)[43]

DE M-SHORAD, also known as Guardian (see **Figure 7**), seeks to integrate a 50 kW laser on a Stryker combat vehicle to provide short-range air defense support to the Army's combat brigades. The Army reportedly tested two DE M-SHORAD prototypes—one from Raytheon/Kord and one from Northrop Grumman—in a "shoot-off" at Ft. Sill, Oklahoma, in July 2021.[44] According to Director of the RCCTO Lieutenant General Neil Thurgood, DE M-SHORAD successfully defeated UAS but failed to defeat mortar rounds during this test; Northrop Grumman subsequently withdrew from the program.[45] The Army tested the Raytheon/Kord prototype again in 2022 during a four-week exercise at White Sands Missile Range, New Mexico and in 2023 during a live-fire test at Yuma Proving Ground.[46] According to a Raytheon press release, the prototype "acquired, tracked, targeted, and defeated multiple mortars and successfully accomplished multiple tests simulating real-world scenarios."[47]

The Army reportedly plans to deliver the first set of DE M-SHORAD prototypes in 2023 and to "begin developing tactics, techniques and procedures for the systems" in the fourth quarter of FY2023.[48] In FY2025, the Army is to transfer the program from the RCCTO to the Program

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[40] This section was written by Andrew Feickert, CRS Specialist in Military Ground Forces.

[41] Lieutenant General (LTG) L. Neil Thurgood, "Space and Missile Defense Symposium," Army Rapid Capabilities and Critical Technologies Office, August 11, 2021.

[42] Nancy Jones-Bonbrest, "Army Advances First Laser Weapon Through Combat Shoot-Off," Army Rapid Capabilities and Critical Technologies Office, August 10, 2021, at https://www.army.mil/article/249239/army_advances_first_laser_weapon_through_combat_shoot_off.

[43] For additional information, see CRS In Focus IF12397, *U.S. Army's Maneuver Short-Range Air Defense (M-SHORAD) System*, by Andrew Feickert.

[44] Jared Keller, "The Army's First Laser Weapon Almost Ready for a Fight," *Task and Purpose*, August 12, 2021; and Ethan Sterenfeld, "Laser M-SHORAD works against mortars in Army test," *Inside Defense*, May 17, 2022.

[45] Evan Oschner, "Army set to deliver first 50-kilowatt lasers," *Inside Defense*, August 10, 2022; and Jen Judson, "Northrop bows out of competition to build laser weapon for Strykers," Defense News, August 18, 2021.

[46] Ethan Sterenfeld, "Laser M-SHORAD works against mortars in Army test," *Inside Defense*, May 17, 2022; and Jen Judson, "Army short-range air defense laser prototypes take down drones at Yuma," *Defense News*, April 13, 2023.

[47] Ethan Sterenfeld, "Laser M-SHORAD works against mortars in Army test," *Inside Defense*, May 17, 2022. See also Jen Judson, "Army short-range air defense laser prototypes take down drones at Yuma," *Defense News*, April 13, 2023.

[48] Jen Judson, "Army short-range air defense laser prototypes take down drones at Yuma," *Defense News*, April 13, 2023.

Executive Office (PEO) Missiles and Space M-SHORAD Product Office.[49] The Product Office is to then "initiate acquisition and contract documents to support a competitive production decision."[50]

Figure 7. Guardian DE M-SHORAD

Source: Kristen Burroughs, "The Army Rapid Capabilities and Critical Technologies Office's Directed Energy Maneuver-Short Range Air Defense (DE M-SHORAD) Rapid Prototyping Effort is On-Track to Deliver," *Army News*, August 18, 2021.

Indirect Fire Protection Capability-High Energy Laser (IFPC-HEL)[51]

IFPC-HEL, also known as Valkyrie (see **Figure 8**), is to protect fixed and semi-fixed sites from cruise missiles, UAS, and RAM threats.[52] According to Army budget documents, the system is to include "a vehicle, 300 kW class [>250 kW] laser subsystem, power and thermal subsystem, and a beam control subsystem integrated with a battle management command, control, and communication software."[53] Army RCCTO issued a request for white papers for IFPC-HEL in January 2022, "with the intent of awarding one or more Other Transaction Agreement for Prototype."[54] Reports indicate that the Army subsequently selected Dynetics to serve as systems

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49 DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Army Justification Book Volume II Budget Activity 4, Research, Development, Test & Evaluation*, p. 563, at https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/rdte/vol_2-Budget_Activity_4.pdf.

50 Ibid., p. 564.

51 For additional information, see CRS In Focus IF12421, *The U.S. Army's Indirect Fire Protection Capability (IFPC) System*, by Andrew Feickert.

52 DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Army Justification Book Volume II Budget Activity 4, Research, Development, Test & Evaluation*, p. 405, at https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/rdte/vol_2-Budget_Activity_4.pdf.

53 DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Army Justification Book Volume II Budget Activity 4, Research, Development, Test & Evaluation*, p. 403, at https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/rdte/vol_2-Budget_Activity_4.pdf.

54 SAM.gov, "Request for White Papers (RFWP) Indirect Fire Protection Capability-High Energy Laser (IFPC-HEL) Prototypes Prime Contractor," January 20, 2022, at https://sam.gov/opp/fe1cce00fde64c328b5234be24c795b1/view. For additional information about Other Transaction Agreements, see CRS Report R45521, *Department of Defense Use of Other Transaction Authority: Background, Analysis, and Issues for Congress*, by Heidi M. Peters.

integrator for IFPC-HEL.[55] Four IFPC-HEL prototypes are to be delivered in the third quarter of FY2025, when IFPC-HEL is to transition to a program of record.[56]

Figure 8. Valkyrie IFPC-HEL

Source: "Dynetics to Build and Increase Power of U.S. Army Laser Weapons," May 7, 2020, https://www.dynetics.com/newsroom/news/2020/dynetics-to-build-and-increase-power-of-us-army-laser-weapons, accessed August 12, 2022.

IFPC-High Power Microwave (IFPC-HPM)[57]

The Army is developing IFPC-HPM (see **Figure 9**)—a transportable, containerized system—to counter swarms of Group 1 and Group 2 UAS.[58] IFPC-HPM is to be "paired with IFPC-HEL as part of a layered defense to protect fixed and semi-fixed sites."[59] According to Army budget documents, the program "leverages previous HPM technology demonstrations and experimentation campaigns such as the [the Air Force's THOR program]."[60] The Army intends to develop, test, and deliver four IFPC-HPM prototypes by the fourth quarter of FY2024 and to conduct planning for a potential transition to a program of record in FY2025.[61]

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[55] Andrew Eversden, "US Army successfully tests Iron Dome at White Sands Missile Range," *Breaking Defense*, August 2, 2022, at https://breakingdefense.com/2022/08/us-army-successfully-tests-iron-dome-at-white-sands-missile-range/.

[56] DOD, *Department of Defense Fiscal Year (FY) 2024 Budget Estimates, Army Justification Book Volume II Budget Activity 4, Research, Development, Test & Evaluation*, p. 344, at https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2024/Base%20Budget/rdte/RDTE-Vol%202-Budget%20Activity%204A.pdf.

[57] For additional information, see CRS In Focus IF12421, *The U.S. Army's Indirect Fire Protection Capability (IFPC) System*, by Andrew Feickert.

[58] DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Army Justification Book Volume II Budget Activity 4, Research, Development, Test & Evaluation*, p. 411, at https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/rdte/vol_2-Budget_Activity_4.pdf. Group 1 UAS are "typically hand-launched, portable systems," while Group 2 UAS are "typically medium-sized, catapult-launched, mobile systems." For additional information about UAS groups, see U.S. Army, *US. Army Unmanned Aircraft Systems Roadmap 2010-2035*, pp. 12-13, at https://irp.fas.org/program/collect/uas-army.pdf.

[59] "Army Directed Energy Strategy," Army Rapid Capabilities and Critical Technologies Office, August 20, 2021.

[60] DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Army Justification Book Volume II Budget Activity 4, Research, Development, Test & Evaluation*, p. 411, at https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/rdte/vol_2-Budget_Activity_4.pdf.

[61] DOD, *Department of Defense Fiscal Year (FY) 2024 Budget Estimates, Army Justification Book Volume II Budget Activity 4, Research, Development, Test & Evaluation*, p. 350, at https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2024/Base%20Budget/rdte/RDTE-Vol%202-Budget%20Activity%204A.pdf.

Lasers on Next-Generation Army Combat Vehicles

Army officials have suggested that next-generation combat vehicles could feature an active protection system employing directed energy to protect the vehicle and to replace traditional mounted weapons.[62] The Army asserts that active protection systems featuring lasers could provide 360-degree protection from incoming rounds or UASs, and that laser weapons might also be used to disable or possibly destroy enemy vehicles. Officials note that to begin fielding Army units with a next-generation combat vehicle in 2035, major decisions would need to be made by 2025. This time frame suggests that the Army has fewer than two years to advance laser weapons technology to a point where it can be considered a viable option, if it is to be incorporated into next-generation combat vehicles.[63]

Selected Navy Directed Energy Programs[64]

The Navy installed its first prototype DE weapon, a 30 kW laser capable of countering small surface craft and UAS, on the USS *Ponce* in 2014.[65] Since then, the Navy has been developing lasers with improved capability for countering surface craft and UAS and is in the process of developing a capability for countering anti-ship cruise missiles (ASCMs). Current Navy DE programs include the following:

- Solid State Laser Technology Maturation (SSL-TM);
- Optical Dazzling Interdictor, Navy (ODIN);
- Surface Navy Laser Weapon System (SNLWS) Increment 1, also known as the High-Energy Laser with Integrated Optical-dazzler and Surveillance (HELIOS); and
- High Energy Laser Counter-ASCM Program (HELCAP).

The Navy's laser development roadmap is illustrated in **Figure 9**.

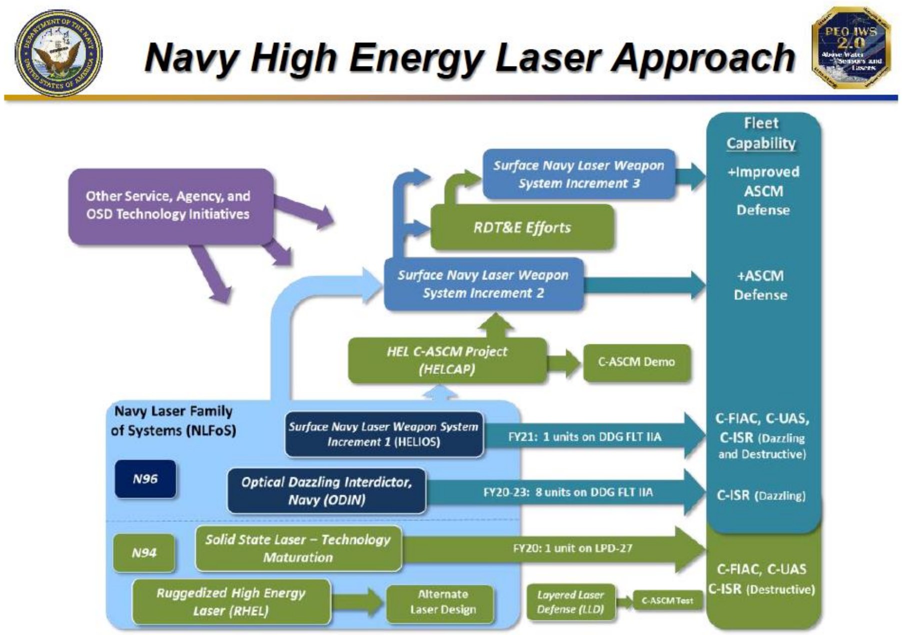
[62] CRS Report R44598, *Army and Marine Corps Active Protection System (APS) Efforts*, by Andrew Feickert.

[63] See Gary Sheftick, "The Next-Generation Combat Vehicle Could Have Lasers, Run on Hybrid Power," *Army News Service*, November 3, 2016, and Hope Hodge Seck, "Next Army Combat Vehicle May Feature Active Protection, Laser Weapons," *Defense Tech*, October 30, 2017.

[64] This section was written by Ronald O'Rourke, CRS Specialist in Naval Affairs. For more information about U.S. Navy DE programs, including information about the Navy's past DE development programs, see CRS Report R44175, *Navy Shipboard Lasers: Background and Issues for Congress*, by Ronald O'Rourke.

[65] Sam LaGrone, "U.S. Navy Allowed to Use Persian Gulf Laser for Defense," *USNI News*, December 10, 2014.

Figure 9. Navy Laser Development Roadmap



Source: Navy briefing slide provided by Navy Office of Legislative Affairs to CRS on August 17, 2022.

As shown in **Figure 9**, SSL-TM, ODIN, and SNLWS Increment 1/HELIOS are included in the Navy Laser Family of Systems (NLFoS). (The Navy has since completed work on the fourth NLFoS effort shown in **Figure 9**, the Ruggedized High Energy Laser [RHEL].) As also shown in **Figure 9**, the Navy intends for both NLFoS and HELCAP efforts, along with DOD laser technologies, to support the development of future, more capable lasers referred to as SNLWS Increment 2 and SNLWS Increment 3.

Solid State Laser Technology Maturation (SSL-TM)

The SSL-TM program (see **Figure 10**) is to develop a prototype shipboard laser called the Laser Weapons System Demonstrator (LWSD) "to address known capability gaps against asymmetric threats (UAS, small boats, and ISR sensors)."[66] The program is to additionally "inform future acquisition strategies, system designs, integration architectures, and fielding plans for laser weapon systems."[67] The Navy reportedly installed a 150 kW LWSD on the USS *Portland* in the fall of 2019 and has since completed onboard testing.[68] According to Navy budget documents, "SSL-TM is planned to start de-installation [of LWSD], ship restoration, and hardware disposition activities during FY23"; the Navy is to complete these activities in FY2024.[69]

[66] DOD, *Department of Defense, Fiscal Year (FY) 2023 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, April 2022, p. 184, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

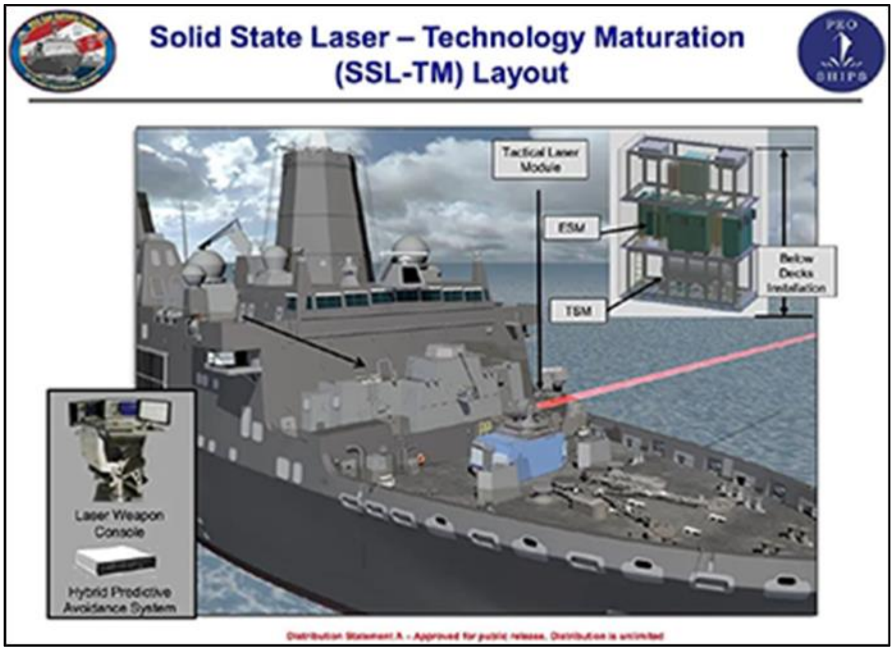
[67] DOD, *Department of Defense, Fiscal Year (FY) 2023 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, April 2022, p. 184, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

[68] Christopher P. Cavas, "Lasers Sprout in San Diego," *Defense & Aerospace Report*, March 1, 2020.

[69] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 182, https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

Additional FY2024 activities are to include completing the final program report (an activity delayed from FY2023), identifying lessons learned, and closing out the program.[70]

Figure 10. Navy Graphic of SSL-TM Laser System



Source: Navy briefing slide accompanying Tyler Rogoway, "Mysterious Object Northrop Is Barging From Redondo Beach Is A High-Power Naval Laser," *The Drive*, October 18, 2019. The blog post credits the slide to the Navy and describes it as a "recent slide."

Optical Dazzling Interceptor, Navy (ODIN)

According to the Navy's FY2024 budget submission, the Optical Dazzling Interceptor, Navy (ODIN) effort is designed to provide "near-term, directed energy, shipboard Counter-Intelligence, Surveillance, and Reconnaissance (C-ISR) capabilities to dazzle UAS and other platforms that address urgent operational needs of the Fleet."[71] The Navy has deployed seven ODIN units on Arleigh Burke Flight IIA destroyers, with plans to deploy an eighth in the fourth quarter of FY2023.[72]

SNLWS Increment 1 (HELIOS)

SNLWS Increment 1 is also known as the High-Energy Laser with Integrated Optical-dazzler and Surveillance (HELIOS). The HELIOS effort is focused on rapid development and rapid fielding of a 60 kW-class high-energy laser (with growth potential to 120 kW) and dazzler in an integrated

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[70] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 183, https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

[71] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 958, at https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

[72] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 993, at https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

weapon system, for use in countering UAS, small boats, and ISR sensors, and for combat identification and battle damage assessment.[73] HELIOS systems integrator Lockheed Martin has stated that HELIOS could eventually be integrated into the Aegis Combat System to provide alternative "selections in [Aegis's] weapon system component."[74] According to Navy budget documents, HELIOS was installed on an Arleigh Burke-class destroyer, the USS *Preble*, in FY2022 and conduct sea trials in FY2023.[75] The system is to remain on the ship for fleet testing and sustainment through at least the end of FY2028.[76]

High Energy Laser Counter ASCM Project (HELCAP)

The Navy's FY2024 budget submission states that the HELCAP effort

> will expedite the development, experimentation, integration and demonstration of critical technologies to defeat crossing Anti-Ship Cruise Missiles (ASCM) by addressing the remaining technical challenges, e.g.: atmospheric turbulence, automatic target identification and aim point selection, precision target tracking with low jitter in high clutter conditions, advanced beam control, and higher power HEL development. HELCAP will assess, develop, experiment, and demonstrate the various laser weapon system technologies and methods of implementation required to defeat ASCMs in a crossing engagement.[77]

The HELCAP prototype system is to include a beam control testbed, 300 kW+ class laser source—selected and adapted from a laser source developed under OSD's laser scaling initiative, prototype control system, and auxiliary prime power and cooling.[78] The Navy plans to conduct system experimentation in FY2023 and FY2024, focusing on "ASCM detect to engage experimentation against targets of increasing complexity up to and including static and dynamic

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[73] DOD, *Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Navy, Justification Book Volume 2 of 5, Research, Development, Test & Evaluation, Navy, February 2020*, p. 1021. Although the Navy previously identified HELIOS as being scalable to 150 kW, recent reports indicate that the system is to be scalable to only 120 kW. See, for example, Richard R. Burgess, "HELIOS Laser Weapon System Delivered for Installation on USS Preble," *Seapower Magazine*, March 31, 2022, at https://seapowermagazine.org/helios-laser-weapon-system-delivered-for-installation-on-uss-preble/.

[74] See Justin Katz, "Lockheed delivers high-energy laser four years in the making to US Navy," *Breaking Defense*, August 18, 2022. For additional information about the Aegis Combat System, see CRS Report RL33745, *Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress*, by Ronald O'Rourke.

[75] DOD, *Department of Defense, Fiscal Year (FY) 2023 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, April 2022, p. 1011, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

[76] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 979, at https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

[77] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 960, at https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

[78] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 962, at https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

ground targets and low-cost unmanned aerial targets."[79] HELCAP experimentation is to continue through at least FY2028.[80]

Layered Laser Defense (LLD) System

An additional Navy laser development effort (not shown in **Figure 9**) is called the Layered Laser Defense (LLD) system. A March 9, 2020, DOD contract award announcement stated that the Navy awarded Lockheed Martin a $22 million contract for

> the integration, demonstration, testing and operation of the Layered Laser Defense (LLD) weapon system prototype onboard a Navy littoral combat ship [LCS] while that vessel is underway.… Key areas of work to be performed include development of a prototype structure and enclosure to protect the LLD from ships motion and maritime environment in a mission module format; system integration and test with government-furnished equipment; platform integration and system operational verification and test; systems engineering; test planning; data collection and analysis support; and operational demonstration.[81]

Press reports indicate that the Office of Naval Research—in partnership with Lockheed Martin and the Office of the Under Secretary of Defense for Research and Engineering—demonstrated the system in February 2022 against a "target representing a subsonic cruise missile in flight."[82] The Navy reportedly does not plan to field the LLD.[83]

Potential Issues and Questions for Congress[84]

Technological Maturity

One question regarding directed energy weapons programs involves their technological maturity, including the ability to improve beam quality and control to militarily useful levels, and to meet size, weight, and power (SWaP) and cooling requirements for integration into current platforms.[85] Some DE systems are small enough to fit on military vehicles, but many require larger and/or fixed platforms that could potentially limit deployment options and operational utility. Congress may consider directing DOD to establish metrics for assessing the pace of technological

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[79] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 961, at https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

[80] DOD, *Department of Defense, Fiscal Year (FY) 2024 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, March 2023, p. 961, at https://www.secnav.navy.mil/fmc/fmb/Documents/24pres/RDTEN_BA4_Book.pdf.

[81] Department of Defense, "Contracts for March 9, 2020." See also Rich Abott, "Lockheed Martin Nabs $22 Million Contract For Layered Laser Defense Prototype On LCS," *Defense Daily*, March 16, 2020.

[82] Warren Duffie Jr., "Laser Trailblazer: Navy Conducts Historic Test of New Laser Weapon System," Office of Naval Research, April, 13, 2022, at https://www.navy.mil/Press-Office/News-Stories/Article/2998829/laser-trailblazer-navy-conducts-historic-test-of-new-laser-weapon-system/.

[83] Warren Duffie Jr., "Laser Trailblazer: Navy Conducts Historic Test of New Laser Weapon System," Office of Naval Research, April, 13, 2022, at https://www.navy.mil/Press-Office/News-Stories/Article/2998829/laser-trailblazer-navy-conducts-historic-test-of-new-laser-weapon-system/.

[84] This section was written by Kelley M. Sayler, CRS Analyst in Advanced Technology and Global Security, and John R. Hoehn, CRS Analyst in Military Capabilities and Programs.

[85] Ariel Robinson, "Directed Energy Weapons: Will They Ever Be Ready?," *National Defense*, July 1, 2015, at https://www.nationaldefensemagazine.org/articles/2015/7/1/2015july-directed-energy-weapons-will-they-ever-be-ready.

advancement. In what ways, if any, are DOD technology maturation efforts reducing the SWaP and cooling requirements of DE systems?

Cost

The United States has been researching directed energy since the 1960s, yet some experts have observed that "actual directed-energy programs … have frequently fallen short of expectations," with DOD investing billions of dollars in programs that failed to reach maturity and were ultimately cancelled.[86] Directed energy weapons may therefore require greater up-front investment than traditional kinetic weapons in order to field a successful weapons system. Congress may consider requesting an independent assessment of the technological maturity and life cycle cost estimates for various DE weapons, as well as a comparative assessment of costs of DE weapons versus comparable kinetic weapons. How do estimates of the total lifecycle costs of DE weapons compare with those of their kinetic counterparts? Does the technological maturity of DE weapons warrant current funding levels?

Weapons Characteristics

Although DE weapons may offer a lower cost per shot than traditional weapons such as missiles, DE weapons are subject to limitations. For example, atmospheric conditions (e.g., rain, fog, obscurants) and SWaP and cooling requirements can limit the range and beam quality of DE weapons, in turn reducing their effectiveness. Traditional weapons, in contrast, are less affected by these factors.[87] Furthermore, DE weapons may be more difficult to maintain than traditional weapons. As the Government Accountability Office notes, "the internal mechanisms for DE weapons are sensitive, and typically require a specialized clean room for repairs."[88] Such challenges could impact their sustainability in the field.[89] How, if at all, might the limitations of DE weapons be mitigated by technological developments such as adaptive optics, concepts of operation, or other methods? What impact might a failure to mitigate these limitations have on future military operations?

Mission Utility

Given the strengths and weaknesses of DE weapons, DOD is conducting multiple utility studies to analyze potential concepts of operation for DE weapons and to assess the scenarios in which they might be militarily useful.[90] How might Congress draw upon the conclusions of these analyses as it conducts oversight of DE weapons programs? What is the appropriate balance between DE weapons and traditional munitions within the military's portfolio of capabilities?

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[86] Paul Scharre, *Directed-Energy Weapons: Promise and Prospects*, Center for a New American Security, April 2015, p. 4.

[87] Ariel Robinson, "Directed Energy Weapons: Will They Ever Be Ready?," *National Defense*, July 1, 2015, at https://www.nationaldefensemagazine.org/articles/2015/7/1/2015july-directed-energy-weapons-will-they-ever-be-ready; and David Vergun, "Army developing lasers that pierce fog, dust to destroy targets," *Army News Service*, October 23, 2017, at https://www.army.mil/article/195650/army_developing_lasers_that_pierce_fog_dust_to_destroy_targets.

[88] Government Accountability Office, *Directed Energy Weapons: DOD Should Focus Transition on Planning*, April 2023, p. 22.

[89] See Jen Judson, "US Army working through challenges with laser weapons," *Defense News*, August 11, 2023, https://www.defensenews.com/land/2023/08/11/us-army-working-through-challenges-with-laser-weapons/.

[90] Dr. Jim Trebes, "Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?," presentation at IDGA, October 21, 2020.

Defense Industrial Base

Some analysts have expressed concerns that, in the past, DOD did not provide stable funding for DE weapons programs or sufficient opportunities for the DE workforce. Acknowledging these concerns, DOD's Principal Director for Directed Energy, Dr. Jim Trebes, has stated that, although he believes the DE industrial base is currently healthy, its capacity could be strained in the future if DOD begins to buy larger numbers of DE systems. Dr. Trebes has noted that although today's DE workforce is sufficient, it may face a demographic problem in the future due to retirement.[91] According to OUSD(R&E), HELSI is intended to address such concerns about the future of the DE industrial base by providing industry with assured prototyping opportunities. In what ways, if any, has HELSI strengthened the defense industrial base for DE weapons? What, if any, challenges does the base continue to face, and how might they be mitigated?

Intelligence Requirements

Some analysts have questioned whether DOD has sufficient knowledge of adversary DE weapons systems and materials to develop its own weapons requirements. DOD is currently attempting to further define its DE collection requirements for the intelligence community (IC) through the Directed Energy Lethality Intelligence initiative.[92] To what extent, if at all, is this initiative improving connectivity between DOD's DE community and the IC? What collection requirements, if any, remain?

Coordination Within DOD

Pursuant to Section 219 of the FY2017 National Defense Authorization Act (NDAA) (P.L. 114-328), OUSD(R&E)'s Principal Director for Directed Energy is tasked with coordinating DE efforts across DOD and with developing DOD's Directed Energy Roadmap, which is to guide development efforts. Section 215 of the FY2020 NDAA (P.L. 116-283) established a Directed Energy Working Group to "analyze and evaluate the current and planned directed energy programs of each of the military departments ... [and] make recommendations to the Secretary of Defense." These recommendations are intended to improve DOD DE coordination activities and accelerate the fielding of DE capabilities. To what extent are the military departments and defense agencies adhering to OUSD(R&E)'s roadmap? What, if any, additional authorities or structural changes would be required to ensure proper implementation of the roadmap and execution of the working group's recommendations?

Arms Control

DE weapons "are not authoritatively defined under international law, nor are they currently on the agenda of any existing multilateral mechanism."[93] However, some applications of DE weapons are prohibited. Article 1 of the Protocol on Blinding Lasers prohibits the employment of "laser

[91] CRS conversation with then-Principal Director for Directed Energy Dr. Jim Trebes, November 17, 2020. See also Dr. Jim Trebes, "Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?," presentation at IDGA, October 21, 2020.

[92] Dr. Jim Trebes, "Advancing High Energy Laser Weapon Capabilities: What is OUSD (R&E) Doing?," presentation at IDGA, October 21, 2020.

[93] "Directed Energy Weapons: Discussion paper for the Convention on Certain Conventional Weapons (CCW)," Article 36, November 2017.

weapons specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision."[94]

Some analysts have suggested that additional multilateral agreements should be considered. For example, Congress may consider prohibitions on nonlethal anti-personnel uses of DE weapons—such as "heat rays"[95] or lasers intended to cause temporary visual impairment—or on certain military applications of DE weapons—such as aircraft interference—in peacetime.[96] Other analysts have argued that DE weapons could be considered more humane than conventional weapons because their accuracy could reduce collateral damage and because they could provide a nonlethal anti-personnel capability in circumstances when lethal force might otherwise be used.[97] In what circumstances and for what purposes should the U.S. military's use of DE weapons be permissible? What, if any, regulations, treaties, or other measures should the United States consider regarding the use of DE weapons in both war and peacetime?

[94] The protocol does not cover the development, procurement, or possession of such weapons, nor does it prohibit the employment of laser weapons that may cause blindness "as an incidental or collateral effect." *Additional Protocol to the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects*, Vienna, October 13, 1995, United Nations, Treaty Series, vol. 1380, p. 370, at https://treaties.un.org/doc/Treaties/1995/10/19951013%2001-30%20AM/Ch_XXVI_02_ap.pdf. For additional information about the protocol and its relationship to DE weapons programs, see Appendix I of CRS Report R41526, *Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress*, by Ronald O'Rourke.

[95] See "Active Denial Technology: Fact Sheet," Joint Intermediate Force Capabilities Office, May 11, 2020, at https://jnlwp.defense.gov/Press-Room/Fact-Sheets/Article-View-Fact-sheets/Article/577989/active-denial-technology/.

[96] Patrick M. Cronin and Ryan D. Neuhard, "Countering China's Laser Offensive," *The Diplomat*, April 2, 2020, at https://thediplomat.com/2020/04/countering-chinas-laser-offensive/.

[97] See, for example, Mark Gunzinger and Chris Dougherty, *Changing the Game: The Promise of Directed-Energy Weapons*, Center for Strategic and Budgetary Assessments, April 19, 2021, at https://csbaonline.org/uploads/documents/CSBA_ChangingTheGame_ereader.pdf.

Appendix A. Potential Advantages and Limitations of Directed Energy Weapons[98]

This appendix provides additional information on potential advantages and limitations of High-Energy Laser (HEL) and High-Powered Microwave (HPM) weapons. The advantages and limitations of any HEL or HPM weapons would be specific to the system; as such, all advantages and limitations might not equally apply to each system.

Potential Advantages of HEL Weapons

In addition to deeper magazines, lower logistics requirements, and lower costs per shot, potential advantages of HEL weapons include the following:

- **Fast engagement times.** Light from a laser beam can reach a target almost instantly, thereby eliminating the need to calculate an intercept course, as interceptor missiles must do. By remaining focused on a particular spot on the target, a laser can cause disabling damage to the target within seconds, depending on the laser power. After disabling one target, a laser can be redirected to another target in several seconds.
- **Ability to counter radically maneuvering missiles.** HEL weapons can follow and maintain their beam on radically maneuvering missiles that might stress the maneuvering capabilities of kinetic interceptors.
- **Precision engagements.** HEL weapons are precision-engagement weapons—the area irradiated by the laser, which might be several millimeters to several inches in diameter, affects what it hits, while generally not affecting (at least not directly) separate nearby objects.
- **Graduated responses.** HEL weapons can perform functions other than destroying targets, including detecting and monitoring targets and producing nonlethal effects, including reversible jamming of electro-optic (EO) sensors. HELs offer the potential for graduated responses that range from warning targets to reversibly jamming their systems, to causing limited but not disabling damage (as a further warning), and then finally causing disabling damage.

Potential Limitations of HEL Weapons

Potential limitations of HEL weapons include the following:

- **Line of sight.** Since laser light passes through the atmosphere on an essentially straight path, HEL weapons would be limited to line-of-sight engagements, and consequently could not counter over-the-horizon targets or targets obscured by intervening objects. As a result, potential engagement ranges against certain targets (e.g., low-flying targets) would be limited.
- **Atmospheric absorption, scattering, and turbulence.** Substances in the atmosphere—particularly water vapor, but also sand, dust, salt particles, smoke, and other air pollution—absorb and scatter light, and atmospheric turbulence can defocus a laser beam. These effects can reduce the effective range of an HEL

[98] This appendix was written by Ronald O'Rourke (HEL weapons) and Andrew Feickert (HPM weapons), CRS Specialist in Naval Affairs and CRS Specialist in Military Ground Forces, respectively.

weapon. Absorption by water vapor is a particular consideration for shipboard lasers because marine environments feature substantial amounts of water vapor in the air. There are certain wavelengths of light (i.e., "sweet spots" in the electromagnetic spectrum) where atmospheric absorption by water vapor is markedly reduced. Lasers can be designed to emit light at or near those sweet spots, so as to maximize their potential effectiveness. Absorption generally grows with distance to target, making it in general less of a potential problem for short-range operations than for longer-range operations. Adaptive optics, which make rapid, fine adjustments to a laser beam on a continuous basis in response to observed turbulence, can counteract the effects of atmospheric turbulence. Even so, lasers might not work well, or at all, in rain or fog, preventing lasers from being an all-weather solution.

- **Thermal blooming.** A laser that continues firing in the same exact direction for a certain amount of time can heat up the air it is passing through, which in turn can defocus the laser beam, reducing its ability to disable the intended target. This effect, called *thermal blooming*, can make lasers less effective for countering targets that are coming straight at them, on a constant bearing (i.e., "down-the-throat" shots). Most tests of laser systems have been against crossing targets rather than "down-the-throat" shots. In general, thermal blooming becomes more of a concern as the power of the laser beam increases.
- **Saturation attacks.** Since a HEL weapon can attack only one target at a time, requires several seconds to disable the target, and requires several more to be redirected to the next one, a HEL weapon can disable only so many targets within a given period of time. This places an upper limit on the ability of an individual laser to deal with saturation attacks—attacks by multiple weapons that approach the platform simultaneously or within a few seconds of one another. This limitation can be mitigated by installing more than one laser on the platform, up to space and energy availability.
- **Hardened targets and countermeasures.** Less powerful lasers—that is, lasers with beam powers measured in kilowatts (kW) rather than megawatts (MW)—can be less effective against targets that incorporate shielding, ablative material, or highly reflective surfaces, or that tumble or rotate rapidly (so that the laser spot does not remain continuously on a single location on the target's surface). Smoke or other obscurants can reduce the susceptibility of a target platform to laser attack. Such measures, however, can increase the cost and/or weight of the target platform.

Potential Advantages of HPM Weapons

In addition to deep magazines, low costs per shot, fast engagement times, and graduated responses, potential advantages of HPM weapons include the following:

- **Temporary or system-specific effects.** HPM weapons can generate waves at different frequencies and power levels to temporarily or permanently disrupt targeted electronic systems while leaving others unaffected.
- **Broad effects.** HPM weapons can destroy a wide array of unshielded electronic systems, including both military and commercial systems. In addition, they are capable of disabling any unshielded electronic system within their

electromagnetic cone (i.e., they can disable numerous systems, including swarms of UAS, at once).

- **Nonlethal applications.** Certain HPM weapons, such as "heat rays," could provide a nonlethal anti-personnel capability in circumstances in which lethal force might otherwise be used.
- **Limitation of collateral damage.** HPM weapons would generate little to no collateral damage of physical structures.[99] This feature could make them attractive weapons in urban areas or in situations "short of war."

Potential Limitations of HPM Weapons

Potential limitations of HPM weapons include the following:

- **Range constraints.** Because HPM beams are more diffuse than lasers and cannot be as tightly focused, the "energy per unit area in HPM beams decreases significantly over distance."[100] This characteristic could limit the range at which HPM weapons are operationally effective.
- **Potential for fratricide.** Because HPM weapons could affect all unshielded electronic systems within range, measures must be taken to ensure that friendly systems are properly shielded or kept outside of the weapon's range when the weapon is in use.
- **Effectiveness of countermeasures.** Because electromagnetic radiation can be absorbed by shielding, HPM weapons may not be effective against shielded targets.

[99] Anti-personnel HPM weapons could not, however, discriminate between military personnel and civilians and could therefore impact civilians within the weapon's electromagnetic cone. Similarly, HPM weapons used against military electronic equipment could disable unshielded civilian equipment.

[100] Mark Gunzinger and Chris Dougherty, *Changing the Game: The Promise of Directed-Energy Weapons*, Center for Strategic and Budgetary Assessments, April 19, 2021, p. 39, at https://csbaonline.org/uploads/documents/CSBA_ChangingTheGame_ereader.pdf.

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