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

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SUMMARY

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

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 a number of 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.

Contents

Figures

Tables

Appendixes

Contacts

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

[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 Analyst 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.

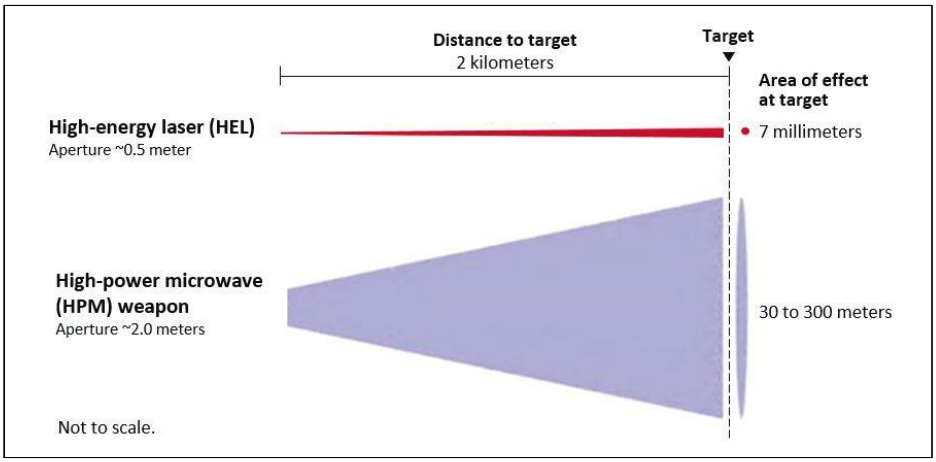
[5] See, for example, James N. Miller and Frank A. Rose, "Bad Idea: Space-Based Interceptors and Space-Based Directed Energy Systems," Center for Strategic and International Studies, December 13, 2018, at https://defense360.csis.org/bad-idea-space-based-interceptors-and-space-based-directed energy-systems/; 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-

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

ready.

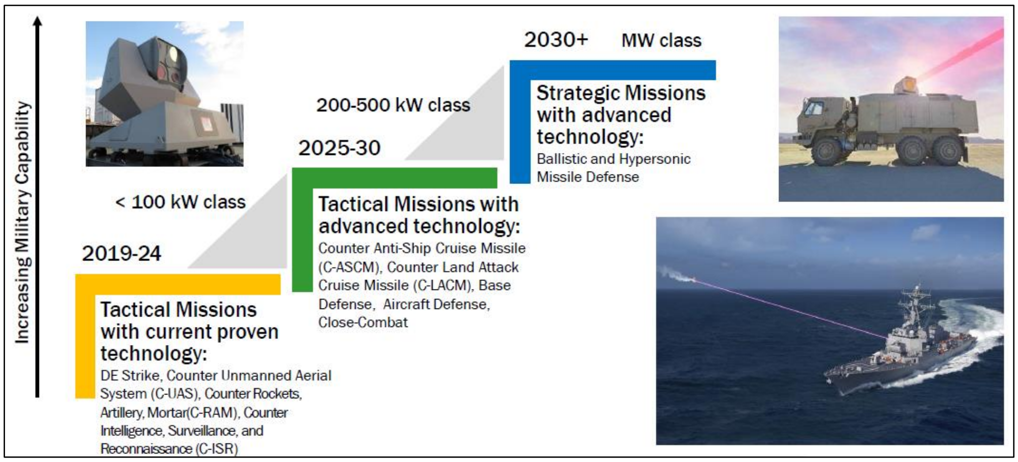
[7] See, for example, Joint Intermediate Force Capabilities Office, "Active Denial System FAQs," https://jnlwp.defense.gov/About/Frequently-Asked-Questions/Active-Denial-System-FAQs/.

[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.

and to further reduce size and weight and increase power to MW [megawatt] levels by 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), and General Atomics (sponsored by the Air Force). See 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.

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

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 "due to a shift in Department of Defense priorities," Congress appropriated $39 million to continuing development efforts.[17] MDA did not request funds for the Directed Energy Demonstrator Development program in FY2023.[18]

In FY2023, 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 $111 million in FY2023 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 $11 million in FY2023 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) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5 Research, Development, Test & Evaluation, Defense-Wide*, pp. 601-602, 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.

[18] 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*, p. 601, 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.

[19] DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Office of the Secretary of Defense, Defense-Wide Justification Book Volume 3 of 5 Research, Development, Test & Evaluation*, pp. 1 and 91, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/03_RDT_and_E/OSD_PB2023.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) 2023 Budget Estimates, Office of the Secretary of Defense, Defense-Wide Justification Book Volume 3 of 5 Research, Development, Test & Evaluation*, p. 327, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/03_RDT_and_E/OSD_PB2023.pdf.

[21] DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Office of the Secretary of Defense, Defense-Wide Justification Book Volume 3 of 5 Research, Development, Test & Evaluation*, p. 348, at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/03_RDT_and_E/OSD_PB2023.pdf.

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

DARPA received $20 million for WARDEN in FY2022 and requested $23 million for the program in FY2023.[23]

Overall, DOD requested at least $669 million in FY2023 for unclassified DE research, development, test, and evaluation (RDT&E)—up from its FY2022 request of at least $578 million and down from its FY2022 appropriation of at least $745 million. The department requested at least $345 million for unclassified DE weapons procurement in FY2023—up from its FY2022 request of at least $332 million and its FY2022 appropriation of at least $325 million.[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.[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) 2023 Budget Estimates, Defense Advanced Research Projects 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.

[24] The dollar amounts in this paragraph include funding for DOD-wide programs as well as programs managed by the Air Force, Army, and Navy. CRS analysis of FY2022 and FY2023 budget documents; see **Appendix B** and **Appendix C** for additional information.

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

[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

[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/.

2020. In contrast to THOR and Phaser, which are designed for a short-range C-UAS mission, the 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]

[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.

Figure 5. HELWS Prototype

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

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]

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[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/.

Figure 6. SHiELD Prototype Rendering

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

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)

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.[43] 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.[44] The Army tested the Raytheon/Kord prototype again

[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] 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.

[44] Evan Oschner, "Army set to deliver first 50-kilowatt lasers," *Inside Defense*, August 10, 2022; and Jen Judson,

in 2022, during a four-week exercise at White Sands Missile Range, New Mexico.[45] According to a Raytheon press release, the prototype "acquired, tracked, targeted, and defeated multiple mortars and successfully accomplished multiple tests simulating real-world scenarios."[46]

The Army plans to deliver the first DE M-SHORAD systems to a Ft. Sill-based air defense unit by the end of September 2022, with plans to deliver additional prototype systems in FY2023 and FY2024.[47] In FY2025, the Army is to transfer the program from the RCCTO to the Program Executive Office (PEO) Missiles and Space M-SHORAD Product Office.[48] The Product Office is to then "initiate acquisition and contract documents to support a competitive production decision."[49]

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)

IFPC-HEL, also known as Valkyrie (see **Figure 8**), is to protect fixed and semi-fixed sites from cruise missiles, UAS, and RAM threats.[50] 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

"Northrop bows out of competition to build laser weapon for Strykers," Defense News, August 18, 2021.

45 Ethan Sterenfeld, "Laser M-SHORAD works against mortars in Army test," *Inside Defense*, May 17, 2022.

46 Ethan Sterenfeld, "Laser M-SHORAD works against mortars in Army test," *Inside Defense*, May 17, 2022.

47 Max Hauptman, "The Army is Putting Lasers on Strykers Powerful Enough to Shoot Down Drones and Helicopter," *Task and Purpose*, January 26, 2022; Evan Ochsner, "Army Set to Deliver First 50-Kilowatt Lasers," *InsideDefense.com,* August 10, 2022; and SAM.gov, "Notice of Intent to Sole Source - DE M-SHORAD Prototype Effort under Other Transaction Agreement," November 17, 2021, at https://sam.gov/opp/3ad5a9cbdba94c6ea2872374bdaefd48/view.

48 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.

49 Ibid., p. 564.

50 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.

communication software."[51] 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."[52] Reports indicate that the Army subsequently selected Dynetics to serve as systems integrator for IFPC-HEL.[53] Four IFPC-HEL prototypes are to be delivered by the fourth quarter of FY2024, with "major test events" scheduled in 2022.[54] IFPC-HEL is to transition to a program of record in FY2025.[55]

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)

The Army is developing IFPC-HPM (see **Figure 9**)—a transportable, containerized system—to counter swarms of Group 1 and Group 2 UAS.[56] IFPC-HPM is to be "paired with IFPC-HEL as part of a layered defense to protect fixed and semi-fixed sites."[57] According to Army budget documents, the program "leverages previous HPM technology demonstrations and

[51] 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.

[52] 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.

[53] 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/.

[54] Jen Judson, "This infantry squad vehicle is getting a laser to destroy drones," *Defense News*, August 11, 2022.

[55] 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.

[56] 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.

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

experimentation campaigns such as the [the Air Force's THOR program]."[58] 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.[59]

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.[60] 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 three 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.[61]

Selected Navy Directed Energy Programs[62]

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.[63] 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**.

[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.

[59] DOD, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Army Justification Book Volume II Budget Activity 4, Research, Development, Test & Evaluation*, p. 412, at https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/rdte/vol_2-Budget_Activity_4.pdf.

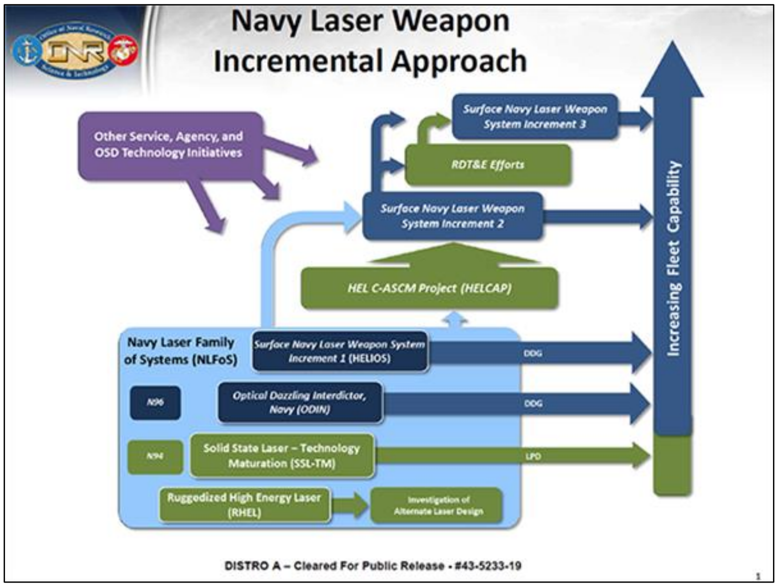
[60] CRS Report R44598, *Army and Marine Corps Active Protection System (APS) Efforts*, by Andrew Feickert.

[61] 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.

[62] 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.

[63] 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 September 10, 2021.

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)."[64] The program is to additionally "inform future acquisition strategies, system designs, integration architectures, and fielding plans for laser weapon systems."[65] The Navy reportedly installed a 150 kW LWSD on the USS *Portland* in the fall of 2019 and has since completed onboard testing.[66] According to Navy budget documents, "SSL-TM is planned to start de-installation [of LWSD], ship restoration, and hardware

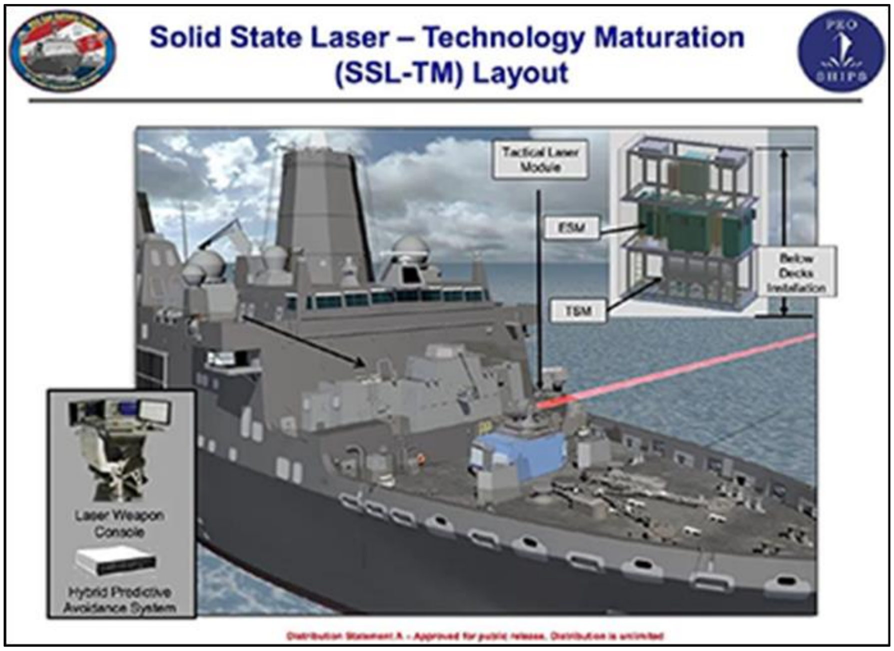
[64] DOD, *Department of Defense, Fiscal Year (FY) 2023 Budget Estimates, Navy Justification Book Volume 2 of 5*, Research, Development, Test & Evaluation, Navy, April 2022, p. 184, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

[65] 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.

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

disposition activities during FY23."[67] Program closeout is to occur by the fourth quarter of FY2024.[68]

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 FY2023 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."[69] The Navy has reportedly deployed seven ODIN units on Arleigh Burke Flight IIA destroyers, with the deployment of one additional unit planned for FY2023.[70]

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[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. 195, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

[68] 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. 200, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

[69] 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. 998, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

[70] 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. 999, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

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 weapon system, for use in countering UAS, small boats, and ISR sensors, and for combat identification and battle damage assessment.[71] 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."[72] According to Navy budget documents, HELIOS was installed on an Arleigh Burke-class destroyer, the USS *Preble*, in FY2022 and is to continue at-sea testing in FY2023.[73] The system is to remain on the ship for fleet testing and sustainment through at least the end of FY2027.[74]

High Energy Laser Counter ASCM Project (HELCAP)

The Navy's FY2023 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.[75]

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.[76] The Navy plans to begin system experimentation in FY2023, focusing on "ASCM detect to engage experimentation against targets of increasing complexity up to and including static and dynamic ground targets

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[71] 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/.

[72] 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.

[73] 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.

[74] 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. 1019, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

[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. 1001, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

[76] 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. 1003, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

and low-cost unmanned aerial targets."[77] HELCAP experimentation is to continue through FY2027.[78]

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.[79]

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."[80] The Navy reportedly does not plan to field the LLD.[81]

Potential Issues and Questions for Congress[82]

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.[83] 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

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77 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. 1003, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

78 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. 1008, at https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/RDTEN_BA4_Book.pdf.

79 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.

80 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/.

81 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/.

82 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.

83 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.

may consider directing DOD to establish metrics for assessing the pace of technological 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.[84] 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 a number of 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.[85] 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.[86] 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?

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

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

[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; 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.

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

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.[87] 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.[88] 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."[89] However, some applications of DE weapons are prohibited. Article 1 of the Protocol on Blinding Lasers prohibits the employment of "laser weapons specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision."[90]

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[87] CRS conversation with 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.

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

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

[90] 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,

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"[91] or lasers intended to cause temporary visual impairment—or on certain military applications of DE weapons—such as aircraft interference—in peacetime.[92] 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.[93] 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?

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.

[91] 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/.

[92] 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/.

[93] 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[94]

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

[94] 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.[95] 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."[96] 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.

[95] 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.

[96] 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.

Appendix B. Funding for Directed Energy Programs[97]

DOD has previously provided limited summary funding information for DE programs in budget documentation. For example, in the FY2020 *Defense Budget Overview* document, the department stated it planned to request $235 million for certain offensive and defensive DE capabilities, including implementing DE applications for base defense, testing and procuring multiple types of lasers, and researching and developing scalable high-power density applications.[98] DOD has not included such funding information in defense budget overview documents since FY2020.

The following sections provide estimates, based on keyword searches, of how much funding DOD has requested for DE programs, how much funding Congress has authorized for these DOD DE programs, and how much funding Congress has appropriated for these programs. CRS is unable to authoritatively identify all DOD funding associated with DE, in part because the department's budget documents do not include standard data elements identifying all funding associated with such work and do not require financial managers to explicitly reference certain words or terms in program and project descriptions.

Determining Funding Levels for Programs

CRS used the Defense Technical Information Center's (DTIC's) DOD Investment Budget Search tool to identify directed energy research, development, test and evaluation (RDT&E) and procurement programs.[99] Search terms included "directed energy" and "lasers."[100] These search terms returned 264 research and development program elements and 90 procurement line items in FY2020. After assessing each of these programs, CRS identified 13 research and development program elements and four procurement line items funding directed energy efforts. Using these results, CRS then traced the funding for these program elements and line items from FY2017 to FY2023.

To assess whether a program element or line item is developing or procuring DE systems, CRS analyzed budget documents. If a program element or line item identified more than 50% of its funding for DE or lasers, it was counted as a DE program listed in **Appendix C**. This approach may have certain methodological challenges. For example, different search terms might include or exclude certain program elements or line items. Inclusion of a program element or line item may overstate the amount of funding involved in DE efforts if, for example, the program element

[97] This appendix was written by John R. Hoehn, CRS Analyst in Military Capabilities and Programs.

[98] DOD, *Department of Defense, Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer, March 2019, Defense Budget Overview, United States Department of Defense Fiscal Year 2020 Budget Request*, pp. 1-9, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2020/fy2020_Budget_Request_Overview_Book.pdf. The document does not, however, detail which specific programs, projects, and activities are associated with this funding. It does not appear to include all of the department's DE programs, projects, and activities.

[99] DOD's Defense Technical Information Center, or DTIC, no longer maintains a publicly accessible website to search procurement and research and development budget documentation (including R-2 and P-40 exhibits). For more information, see Jason Sherman, "DOD moves Google-like tool for searching U.S. military weapon spending behind firewall," *Inside Defense*, November 3, 2020, at https://insidedefense.com/daily-news/dod-moves-google-tool-searching-us-military-weapon-spending-behind-firewall.

[100] Due to database access limitations, CRS was unable to conduct a search for "microwave."

or line item supports other purposes. These results therefore should be considered illustrative and not comprehensive or exact.

After identifying specific program elements and line items, CRS used the National Defense Authorization Acts from FY2017 through FY2022 to identify how much each program element or line item was authorized to receive in a given fiscal year. CRS used two methods to identify appropriated amounts for each program element or line item. First, DOD typically reports appropriated amounts from the two previous fiscal years when it requests funding in budget justifications. FY2019 through FY2022 budget justification documentation provided appropriation amounts for FY2017 through FY2020.[101] For FY2021 and FY2022 appropriations, CRS analyzed funding tables in the Joint Explanatory Statement accompanying the respective Department of Defense Appropriations Acts (P.L. 116-260 and P.L. 117-103).[102]

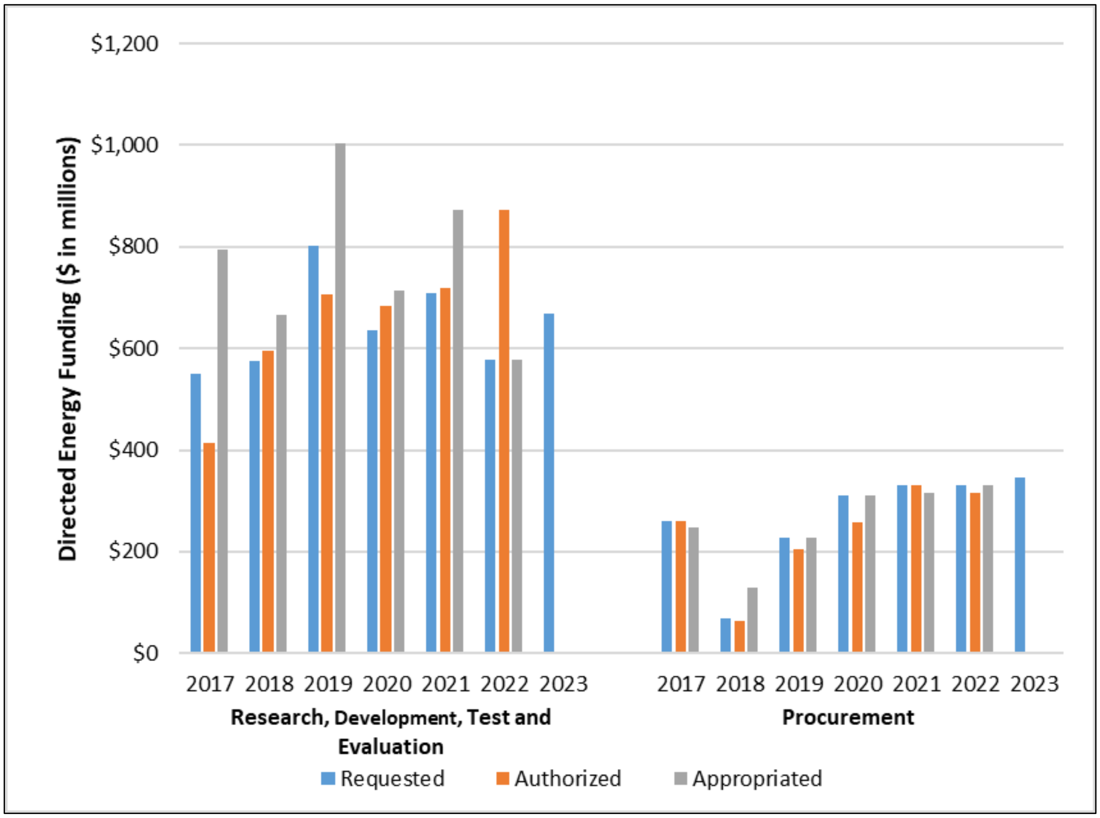
Analysis

Figure B-1 depicts the differences between the President's budget request and congressional authorizations and appropriations in RDT&E and procurement across five fiscal years. Program element and line item funding are combined to provide an overview of the appropriation category. Individual program elements or line items trends may differ from the overview depicted below. **Appendix C** provides a detailed list of RDT&E program elements and procurement line items.

[101] When available, this report uses the "actual" values reported in the DOD budget justifications because the data reported represent both congressional appropriations and congressionally approved reprogramming decisions. Thus the "actuals" are a more complete representation of congressional action on an individual program.

[102] The Joint Explanatory Statement accompanying P.L. 116-93, *Congressional Record,* December 17, 2019, https://www.govinfo.gov/content/pkg/CREC-2019-12-17/pdf/CREC-2019-12-17-house-bk2.pdf; and H.Rept. 116-453, and Joint Explanatory Statement accompanying P.L. 117-103, *Congressional Record*, March 9, 2022, at https://docs.house.gov/floor/Default.aspx?date=2022-03-07.

Figure B-1. Requested, Authorized, and Appropriated Funding Levels for Selected DE Programs



Source: CRS analysis of FY2017-FY2023 Army, Air Force, Navy, and Defense-Wide Research, Development, Test and Evaluation and Procurement Budget Justifications, P.L. 114-328, P.L. 115-91, P.L. 115-232, P.L. 116-92, P.L. 116-93, P.L. 116-260, P.L. 116-283, P.L. 117-81 and P.L. 117-103.

Note: Funding levels are in current U.S. dollars.

The military services sometimes change the funding source for programs and activities, including those related to DE. Two program elements in particular from FY2017 through FY2019 were significantly restructured: Electronics and Electronic Devices (PE 0602705A) and Weapons and Munitions Advanced Technology (PE 0603004A). These two program elements funded a number of DE projects, which were shifted into multiple new program elements to support the Army's new modernization strategy. Based on FY2020 budget documents, these projects now primarily reside in Air and Missile Defense Technology (PE 0602150A) and Air and Missile Defense Advanced Technology (PE 0603466A). These new program elements fund a number of other projects, but these alignments appear to provide the best linkage to historical programs.[103] There were no changes to programs in FY2023.

Many of the programs identified in this analysis appear to be defensive countermeasures designed to protect aircraft. The Air Force's Large Aircraft Infrared Countermeasures, the Army's Common Infrared Countermeasures, and the Navy's Tactical Air Directed Infrared Countermeasures are examples of these countermeasures. Other examples of DE programs

[103] Figures document total funding in a program element or line item. Due to the data fidelity of FY2020 appropriations, CRS was unable to assess DE funding at the project level.

include the Army's Maneuver-Short Range Air Defense (M-SHORAD) and the Air Force's Threat Simulator Development.

Reviewing funding for FY2022, CRS noted several issues related to both procurement and research and development. Using this methodology, it appears that the Biden Administration requested approximately $909 million,[104] was authorized $1,052 million, and was appropriated $1,070 million. The deviation in FY2022 funding between authorization and appropriation levels and the President's budget request can largely be attributed to two research and development programs, which received relatively large increases in appropriations compared with the request: (1) the Air Force's Air and Missile Defense Advanced Technology ($97 million) and (2) the Army's Air and Missile Defense ($74 million). Other smaller increases and decreases are predominately offsetting.

Two additional trends occur across the two appropriation categories. First, it appears that DE research and development programs received additional appropriations compared with both the requested amount and the authorized amount. Second, programs that were in procurement over the previous four years seem to have been appropriated less funding than was requested, though on average it appears that appropriations have been larger than authorizations.

[104] The FY2023 budget request did not provide an estimate for directed energy programs. However, the Trump Administration stated in its FY2020 budget request that it funded $235 million in DE programs, whereas CRS calculated the Administration's request to be $634 million. The difference between these two funding levels is most likely based on methodological differences.

Appendix C. List of Selected Line Items and Program Elements[105]

Table C-1. Selected Directed Energy Procurement Line Items

Title	Agency	Fiscal Year	Line Item	Requested ($ in thousands)	Authorized ($ in thousands)	Appropriated ($ in thousands)
Large Aircraft Infrared Countermeasures (CM)	Air Force	2023	LAIRCM	25,286	—	—
Large Aircraft Infrared CM	Air Force	2022	LAIRCM	57,001	57,001	57,001
Large Aircraft Infrared CM	Air Force	2021	LAIRCM	57,521	57,521	46,321
Large Aircraft Infrared CM	Air Force	2020	LAIRCM	97,093	53,335	97,093
Large Aircraft Infrared CM	Air Force	2019	LAIRCM	149,778	149,778	149,778
Large Aircraft Infrared CM	Air Force	2018	LAIRCM	4,046	4,066	4,066
Large Aircraft Infrared CM	Air Force	2017	LAIRCM	135,801	135,801	135,801
Common Infrared CM (CIRCM)	Army	2023	5399AZ3537	288,209	—	—
CIRCM	Army	2022	5399AZ3537	240,412	238,012	234,012
CIRCM	Army	2021	5399AZ3537	237,467	237,464	234,117
CIRCM	Army	2020	5399AZ3537	178,094	168,784	178,094
CIRCM	Army	2019	5399AZ3537	60,899	36,839	60,899
CIRCM	Army	2018	AZ3537	49,777	43,440	108,721
CIRCM	Army	2017	AZ3537	108,721	108,721	80,677
Survivability CM	Army	2023	5044AZ3507	6,622	—	—
Survivability CM	Army	2022	5044AZ3507	5,104	5,104	5,104
Survivability CM	Army	2021	5044AZ3507	8,035	8,035	8,035
Survivability CM	Army	2020	5044AZ3507	8,388	8,388	8,388
Survivability CM	Army	2019	5044AZ3507	5,853	5,853	5,853
Survivability CM	Army	2018	AZ3507	5,884	5,884	5,884
Survivability CM	Army	2017	AZ3507	9,565	9,565	9,565
MAGTF EW for Aviation	Navy	2023	0587	24,684	—	—

[105] This appendix was written by John R. Hoehn, CRS Analyst in Military Capabilities and Programs.

Title	Agency	Fiscal Year	Line Item	Requested ($ in thousands)	Authorized ($ in thousands)	Appropriated ($ in thousands)
MAGTF EW for Aviation	Navy	2022	0587	29,151	29,151	29,151
MAGTF EW for Aviation	Navy	2021	0587	27,794	27,794	26,822
MAGTF EW for Aviation	Navy	2020	0587	26,536	26,536	26,536
MAGTF EW for Aviation	Navy	2019	0587	11,590	11,590	11,590
MAGTF EW for Aviation	Navy	2018	0587	10,111	10,111	10,111
MAGTF EW for Aviation	Navy	2017	0588	5,676	5,676	21,968

Source: CRS analysis of FY2017-FY2022 Army, Air Force, Navy, and Defense-Wide Research, Development, Test and Evaluation and Procurement Budget Justifications, P.L. 114-328, P.L. 115-91, P.L. 115-232, P.L. 116-92, and P.L. 116-93.

Notes: Blank cells represent data that were not available at the time of publication. MAGTF EW stands for Marine Air Ground Task Force Electronic Warfare.

Table C-2. Selected Directed Energy Research, Development, Test and Evaluation Program Elements

Title	Agency	Fiscal Year	Program Element	Requested ($ in thousands)	Authorized ($ in thousands)	Appropriated ($ in thousands)
Directed Energy Prototyping	Air Force	2023	0604032F	4,269	—	—
Directed Energy Prototyping	Air Force	2022	0604032F	10,820	10,820	15,820
Directed Energy Prototyping	Air Force	2021	0604032F	20,964	20,964	19,464
Directed Energy Prototyping	Air Force	2020	0604032F	10,000	20,000	42,390
Directed Energy Prototyping	Air Force	2019	0604032F	—	—-	50,000
Directed Energy Prototyping	Air Force	2018	0604032F	—	—	—
Directed Energy Prototyping	Air Force	2017	0604032F	—	—	—
Directed Energy Technology	Air Force	2023	0602605F	109,302	—	—
Directed Energy Technology	Air Force	2022	0602605F	121,869	113,522	116,456
Directed Energy Technology	Air Force	2021	0602605F	128,113	128,113	130,613
Directed Energy Technology	Air Force	2020	0602605F	32,020	124,379	114,279
Directed Energy Technology	Air Force	2019	0602605F	33,506	141,898	141,800
Directed Energy Technology	Air Force	2018	0602605F	33,047	141,293	132,993
Directed Energy Technology	Air Force	2017	0602605F	127,163	127,163	127,365
High Energy Laser Research[a]	Air Force	2022	0602890F	—	—	—
High Energy Laser Research	Air Force	2021	0602890F	45,088	45,088	29,208
High Energy Laser Research	Air Force	2020	0602890F	44,221	44,221	47,462
High Energy Laser Research	Air Force	2019	0602890F	43,359	45,859	43,192
High Energy Laser Research	Air Force	2018	0602890F	43,049	43,049	43,049
High Energy Laser Research	Air Force	2017	0602890F	42,300	42,300	39,545
High Energy Laser Research Initiatives[b]	Air Force	2022	0601108F	—	—	—

Title	Agency	Fiscal Year	Program Element	Requested ($ in thousands)	Authorized ($ in thousands)	Appropriated ($ in thousands)
High Energy Laser Research Initiatives	Air Force	2021	0601108F	15,085	15,085	15,085
High Energy Laser Research Initiatives	Air Force	2020	0601108F	14,795	14,795	13,736
High Energy Laser Research Initiatives	Air Force	2019	0601108F	14,506	14,506	13,106
High Energy Laser Research Initiatives	Air Force	2018	0601108F	14,417	14,417	14,417
High Energy Laser Research Initiatives	Air Force	2017	0601108F	14,168	14,168	13,224
Large Aircraft IR Countermeasures (LAIRCM)	Air Force	2023	0401134F	2,909	—	—
LAIRCM	Air Force	2022	0401134F	5,504	5,504	5,504
LAIRCM	Air Force	2021	0401134F	5,507	5,507	5,507
LAIRCM	Air Force	2020	0401134F	5,424	5,424	5,247
LAIRCM	Air Force	2019	0401134F	4,334	4,334	4,334
LAIRCM	Air Force	2018	0401134F	5,283	5,283	5,095
LAIRCM	Air Force	2017	0401134F	5,166	5,166	5,011
Threat Simulator Development	Air Force	2023	0604256F	21,607	—	—
Threat Simulator Development	Air Force	2022	0604256F	41,909	41,909	46,909
Threat Simulator Development	Air Force	2021	0604256F	57,725	57,725	57,725
Threat Simulator Development	Air Force	2020	0604256F	59,693	59,693	58,906
Threat Simulator Development	Air Force	2019	0604256F	34,256	34,256	34,206
Threat Simulator Development	Air Force	2018	0604256F	35,405	35,405	35,405
Threat Simulator Development	Air Force	2017	0604256F	21,630	21,630	21,377
Air and Missile Defense Advanced Technology	Army	2023	0603466A	11,147	—	—
Air and Missile Defense Advanced Technology	Army	2022	0603466A	48,826	68,826	145,826
Air and Missile Defense Advanced Technology	Army	2021	0603466A	58,130	73,630	182,630

Title	Agency	Fiscal Year	Program Element	Requested ($ in thousands)	Authorized ($ in thousands)	Appropriated ($ in thousands)
Air and Missile Defense Advanced Technology	Army	2020	0603466A	60,613	60,613	79,817
Weapons and Munitions Advanced Technology	Army	2019	0603004A	102,686	122,686	241,581
Weapons and Munitions Advanced Technology	Army	2018	0603004A	84,709	84,079	84,079
Weapons and Munitions Advanced Technology	Army	2017	0603004A	68,714	68,714	198,245
Air and Missile Defense Technology	Army	2023	0602150A	27,016	—	—
Air and Missile Defense Technology	Army	2022	0602150A	19,316	72,566	93,566
Air and Missile Defense Technology	Army	2021	0602150A	56,298	66,298	109,298
Air and Missile Defense Technology	Army	2020	0602150A	50,771	50,771	19,316
Common Infrared Countermeasures (CIRCM)	Army	2023	0605035A	11,523	—	—
CIRCM	Army	2022	0605035A	16,630	16,630	16,630
CIRCM	Army	2021	0605035A	23,321	28,321	28,321
CIRCM	Army	2020	0605035A	46,258	11,770	22,226
CIRCM	Army	2019	0605035A	53,848	2,670	33,809
CIRCM	Army	2018	0605035A	127,318	21,540	97,746
CIRCM	Army	2017	0605035A	107,877	10,900	127,318
Electronics and Electronic Devices	Army	2019	0602705A	58,283	58,283	96,760
Electronics and Electronic Devices	Army	2018	0602705A	58,352	60,352	90,613
Electronics and Electronic Devices	Army	2017	0602705A	56,322	56,322	72,979
Maneuver - Short Range Air Defense (M-SHORAD)	Army	2023	0604117A	225,147	—	—
M-SHORAD	Army	2022	0604117A	39,376	39,376	39,376
M-SHORAD	Army	2021	0604117A	4,995	4,995	4,995
M-SHORAD	Army	2020	0604117A	39,100	29,400	41,690
M-SHORAD	Army	2019	0604117A	118,085	23,000	79,016
M-SHORAD	Army	2018	0604117A	20,000	20,000	19,201

Title	Agency	Fiscal Year	Program Element	Requested ($ in thousands)	Authorized ($ in thousands)	Appropriated ($ in thousands)
M-SHORAD	Army	2017	0604117A	—	—	95,085
Directed Energy and Electric Weapon System	Navy	2023	0603925N	65,080	—	—
Directed Energy and Electric Weapon System	Navy	2022	0603925N	71,803	81,803	81,803
Directed Energy and Electric Weapon System	Navy	2021	0603925N	128,845	128,845	126,895
Directed Energy and Electric Weapon System	Navy	2020	0603925N	118,169	118,169	136,535
Directed Energy and Electric Weapon System	Navy	2019	0603925N	223,344	142,412	142,814
Directed Energy and Electric Weapon System	Navy	2018	0603925N	107,310	122,310	92,856
Directed Energy and Electric Weapon System	Navy	2017	0603925N	32,700	32,700	34,039
Tact Air Dir Infrared CM (TADIRCM)	Navy	2023	0604272N	15,028	—	—
TADIRCM	Navy	2022	0604272N	33,246	33,246	33,246
TADIRCM	Navy	2021	0604272N	59,776	52,026	50,281
TADIRCM	Navy	2020	0604272N	68,346	58,449	54,175
TADIRCM	Navy	2019	0604272N	47,278	47,278	47,278
TADIRCM	Navy	2018	0604272N	46,589	46,844	51,311
TADIRCM	Navy	2017	0604272N	72,910	34,920	59,753
High Energy Laser Advanced Development	OSD	2023	0603924D8Z	111,149	—	—
High Energy Laser Advanced Development	OSD	2022	0603924D8Z	107,397	107,397	83,497
High Energy Laser Advanced Development	OSD	2021	0603924D8Z	105,410	92,270	112,910
High Energy Laser Advanced Development	OSD	2020	0603924D8Z	85,223	85,223	78,057
High Energy Laser Advanced Development	OSD	2019	0603924D8Z	69,533	69,533	74,364

Title	Agency	Fiscal Year	Program Element	Requested ($ in thousands)	Authorized ($ in thousands)	Appropriated ($ in thousands)
High Energy Laser Advanced Development	OSD	2018	0603924D8Z	—	—	—
High Energy Laser Advanced Development	OSD	2017	0603924D8Z	—	—	—
High Energy Laser Development	OSD	2023	0602890D8Z	48,587	—	—
High Energy Laser Development	OSD	2022	0602890D8Z	45,997	115,997	45,997
High Energy Laser Research Initiatives	OSD	2023	0601108D8Z	16,257	—	—
High Energy Laser Research Initiatives	OSD	2022	0601108D8Z	15,390	15,390	20,390

Source: CRS analysis of FY2017-FY2022 Army, Air Force, Navy, and Defense-Wide Research, Development, Test and Evaluation and Procurement Budget Justifications, P.L. 114-328, P.L. 115-91, P.L. 115-232, P.L. 116-92, and P.L. 116-93.

Notes: Blank cells represent data that were not available at the time of publication. Tact Air Dir Infrared stands for Tactical Aircraft Directable Infrared.

a. Funding transferred to OSD High Energy Laser Development (0602890D8Z) in FY2022.

b. Funding transferred to OSD High Energy Laser Research Initiatives (0601108D8Z) in FY2022.

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