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# U.S. Army Weapons-Related Directed Energy (DE) Programs: Background and Potential Issues for Congress

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# Summary

The U.S. military has a long and complicated history in developing directed energy (DE) weapons. Many past efforts have failed for a variety of reasons and not all failures were attributed to scientific or technological challenges associated with weaponizing DE. At present, a number of U.S. military DE weapons-related programs are beginning to show promise, such as the Navy's Laser Weapon System (LaWs), the first ever Department of Defense (DOD) laser weapon to be deployed and approved for operational use, according to the Navy. With a number of U.S. Army weapons-related DE programs showing promise during concept demonstrations and their potential relevance in addressing a number of current and emerging threats to U.S. ground forces, some believe the Army is making progress to field viable DE weapon systems designed to counter rockets, artillery, and mortars (C-RAM) and address certain types of short-range air defense (SHORAD) threats.

While DE weapons offer a variety of advantages over conventional kinetic weapons including precision, low cost per shot, and scalable effects, there are also some basic constraints, such as beam attenuation, limited range, and an inability to be employed against non-line-of-sight targets, that will need to be addressed in order to make these weapons effective across the entire spectrum of combat operations.

DE weapon system development raises a number of national security and international relations implications associated with DE weapons as well as international law concerns that must also be taken into account. By no means does the United States enjoy a monopoly on DE weapons development, and potential adversaries such as Russia and China, as well as allies such as Israel, have well-established DE weapons programs that, in some cases, might be on par with or even surpass current U.S. DE weapons development programs, presenting additional national security concerns to U.S. policymakers.

Potential issues for Congress include the following:

- What progress has been made on Army weapons-related high powered microwave (HPM) programs?
- How do U.S. Army DE efforts compare to our allies and potential adversaries?
- How close is the Army to fielding operational DE weapon systems?
- How practical are these systems given their constraints?
- How will the Army's new Modernization Command affect the management of weapons-related DE programs?
- What are the estimates of resources needed to fund the Army's full suite of DE systems?

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# Why This Issue Has Been Important to Congress

Congress has had a long-standing interest in Department of Defense (DOD) efforts to develop directed energy (DE) weapons. Past DOD programs, such as the U.S. Air Force's Airborne laser (ABL) program and the Reagan-era Strategic Defense Initiative (SDI), and current programs, such as the U.S. Navy's Laser Weapon System (LaWS),[1] have been subject to rigorous congressional oversight. Interest in U.S. military DE efforts in Congress resulted in the establishment of the Congressional Directed Energy Caucus in November 2011 to oversee DOD DE activities.

With a number of U.S. Army weapons-related DE programs showing promise during concept demonstrations and their potential relevance in addressing a number of current and emerging threats to U.S. ground forces, congressional oversight could focus on programmatic developments and timelines as well as related authorization and appropriations issues.

# What Are DE Weapons?

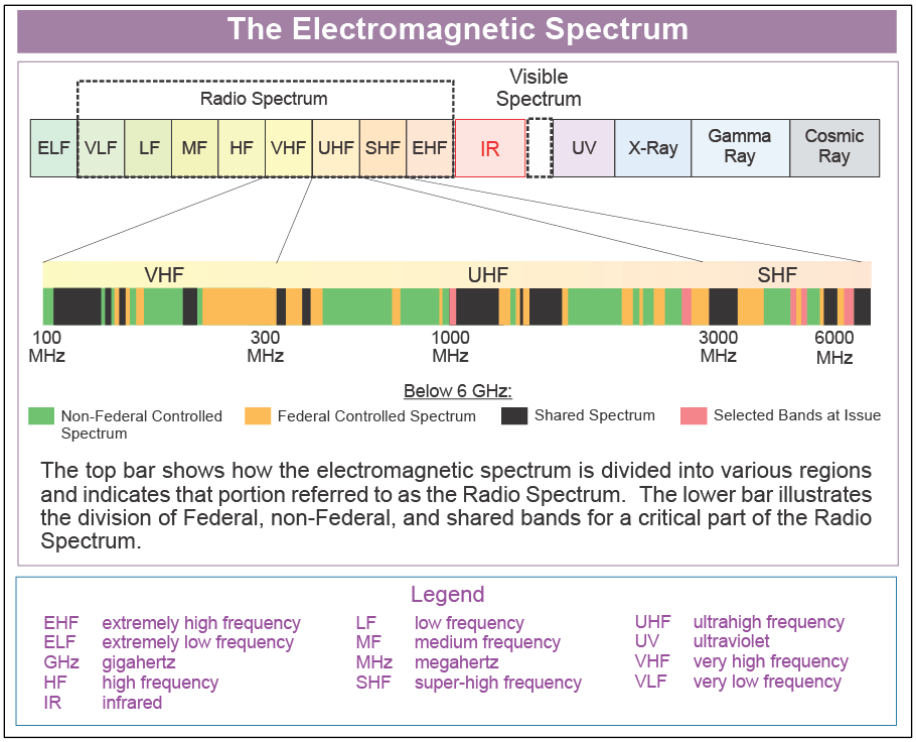
According to DOD

> DE is an umbrella term covering technologies that produce concentrated electromagnetic (EM) energy and atomic or subatomic particles. A DE weapon is a system using DE primarily as a means to incapacitate, damage, disable, or destroy enemy equipment, facilities, and/or personnel. Directed-energy warfare (DEW) is military action involving the use of DE weapons, devices, and countermeasures to incapacitate, cause direct damage or destruction of adversary equipment, facilities, and/or personnel, or to determine, exploit, reduce, or prevent hostile use of the electromagnetic spectrum (EMS) **(see Figure 1)** through damage, destruction, and disruption. It also includes actions taken to protect friendly equipment, facilities, and personnel and retain friendly use of the EMS. With the maturation of DE technology, weaponized DE systems are becoming more prolific, powerful, and a significant subset of the electronic warfare (EW) mission area. DE examples include active denial technology, lasers, radio frequency (RF) weapons, and DE anti-satellite and high-powered microwave (HPM) weapon systems.[2]

[1] For additional information on the Navy's Laser Weapon System see CRS Report R44175, *Navy Lasers, Railgun, and Hypervelocity Projectile: Background and Issues for Congress*, by Ronald O'Rourke.

[2] Joint Chiefs of Staff, Electronic Warfare, Joint Publication 3-13.1, February 8, 2012, p. 1-16.

**Figure 1. Electromagnetic Spectrum (EMS)**




**Source:** Joint Chiefs of Staff, Electronic Warfare, Joint Publication 3-13.1, February 8, 2012, p. I-2.

This report examines the two most prevalent types of DE weapons: High Energy Lasers (HELs) and High Powered Microwaves (HPMs).

# National Security Implications of DE Weapons[3]

DE weapons have the potential to change the very nature of warfare and could have implications for U.S. national security. Some of these potential implications are as follows:

- DE could be used as both a sensor and a weapon, thereby shortening the sensor-to-shooter timeline to seconds. This means that U.S. weapon systems could conduct multiple engagements against a target before an adversary could respond.
- Airborne HELs could change the nature of air combat. Aircraft with HELs could engage ballistic missiles, surface-to-air missiles (SAMs), and other airborne platforms. HELs could also be employed on stealthy unmanned combat aerial vehicles (UCAVs), enabling precision strikes against a wide variety of highly defended enemy targets. HPMs could also be used to defend U.S. aircraft against SAMs.
- DE could also significantly improve U.S. suppression of enemy air defense (SEAD) operations, permitting, under certain circumstances, the United States to achieve air dominance over an adversary in a few days or a couple of weeks. DE weapons could rapidly locate and attack mobile SAM systems. HPM weapons

[3] Unless otherwise noted, information in this section is taken from "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, pp. 33-35.

could significantly improve antiradiation attack capabilities and defeat efforts by enemy air defense systems to evade detection and attack by turning off their systems.

- DE weapons could prove an important advancement in missile defense. DE weapons could be highly effective as part of a boost-phase defense and could, if successfully developed, serve as a cost-effective counter to enemy ballistic missiles as well as associated countermeasures such as decoys and maneuverable warheads.
- DE weapons could have the potential to preempt enemy use of weapons of mass destruction (WMD). HPM weapons, in particular, could be used to attack WMD facilities that are buried, hardened, or co-located with civilian populations or infrastructure.
- DE weapons, particularly HPM weapons, could enhance the ability of the United States to conduct precise, effects-based operations. DE weapons could address one of the most problematic asymmetric strategies employed by adversaries: use of civilians as shields. Although HELs offer a precision strike capability to help reduce civilian casualties, HPMs could attack virtually any electronic system without doing direct harm to nearby civilians.
- DE weapons could facilitate new strategic operations such as disrupting power generation and distribution. DE weapons could be used in selected strategic strikes against industrial systems and military infrastructure dependent on electric power and electronic systems. Effects could range from short-term disruption of service to subsystem destruction.
- DE weapons could also provide a means by which the U.S. military could achieve limited space control. Defensively, DE weapons could provide protection of U.S. and allied space-based assets. Employed offensively, DE weapons could temporarily deny the use of space assets by adversaries and damage or destroy enemy satellites.

# International Relations Implications of DE Weapons[4]

Although it is difficult to predict how DE weapons could affect international relations—primarily because many of these technologies are in development—there are some general observations that may be useful for policymakers. These observations, however, are predicated on the assumption that DE programs presently being developed will eventually overcome any technological challenges that are preventing them from being fielded as viable weapon systems.

Early DE weapon applications will likely be both tactical and defensive in nature, whether for missile defense or for counter rocket, artillery, and mortars (C-RAM) applications, for example. These weapons will likely have little effect on the international environment for that very reason. Some argue these weapons could exert a stabilizing influence on international affairs "by offering non-offensive means of responding to threats posed by theater ballistic missiles, short-range rockets and even long-ranged artillery fire."[5]

[4] Ibid., pp. 38-42.

[5] Ibid., p. 38.

However, if DE weapons become more common and effective and possibly take on a more offensive role, their effect on military operations and international relations could grow. As previously noted, DE weapons represent a transformative capability in a number of military domains, perhaps fundamentally altering the nature of combat and putting other nations at a severe military disadvantage. In the case of air combat, incorporating DE weapons on U.S. aircraft, from an adversary's perspective, "could negate billions of dollars of investment in both tactical fighters and SAMs," suggesting that "nations that wish to deploy credible, effective air power will have to consider how they can acquire DE capabilities."[6] In a sense, if DE weapons become more commonplace, a DE "arms race" could ensue.

One particular realm where DE weapons could have a profound international relations affect as well as shape U.S. foreign policy is in the area of space control.[7] In a space role, DE could potentially be used defensively to attack enemy antisatellite systems targeted against U.S. space systems and offensively could potentially be used to interfere with or destroy enemy satellites. Such an unchallenged ability to exert space control "could dramatically impact military balances and the course of future conflicts."[8] The possibility, however, of such "conflict in space" is not without significant controversy, as many here and abroad oppose the "weaponization of space"—a domain many view as a shared common environment where all nations should have unfettered access. As the most extensive user of space for national security purposes, the United States is particularly vulnerable to attacks against its space-based assets, making this domain of critical concern to both defense officials and policymakers.

# DE Weapons and International Agreements

A discussion paper drafted for the Convention on Certain Conventional Weapons (CCW) noted the following:

> Directed Energy Weapons (DEW) are not authoritatively defined under international law, nor are they currently on the agenda of any existing multilateral mechanism. Nevertheless, there are a number of legal regimes which would apply to DEW. These range from national civilian use regulations and guidelines to international humanitarian law (IHL) and human rights law that would constrain or preclude their use under certain circumstances.[9]

Selected international regimes that apply to DE weapons include the following:

## Convention on Certain Conventional Weapons (CCW)[10]

Protocol IV of the CCW "Protocol on Blinding Lasers" states the following:

[6] Ibid., p. 39.

[7] The Defense Science Board defines space control as the ability of the United States to maintain free access to and use of outer space and, simultaneously, to deny the use of space to adversaries.

[8] "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, p. 39.

[9] Discussion Paper "Directed Energy Weapons," Article 36 Discussion Paper for the Convention on Certain Conventional Weapons, Geneva, November 2017, p. 5.

[10] Protocols Between the United States of America and Other Governments to the Convention on the Use of Certain Conventional Weapons Which may be Deemed Excessively Injurious or to Have Indiscriminate Effects of October 10, 1980, Adopted in Vienna October 13, 1995.

> It is prohibited to employ laser weapons specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision that is to the naked eye or to the eye with corrective eyesight devices.[11]

In this regard, lasers that do not fall under Protocol IV are considered legitimate weapons of war.[12] However, it can be argued that as new applications for DE weapons are developed, they could conceivably inflict casualties considered by some to be "excessively injurious" as described by the CCW and, thereby, possibly viewed as illegal. A counterargument to DE weapons being categorized as "excessively injurious" is that they could be considered more humane than conventional weapons since they can strike targets with pinpoint accuracy, thereby causing less collateral damage.[13] Furthermore, lower-power nonlethal uses for HELs and HPMs merit consideration as well.[14] Under these circumstances, both DOD and the Army could find it beneficial to ensure new DE weapons programs are in accordance with the provisions of Protocol IV of the CCW and avoid effects that could be deemed as "excessively injurious."

### Outer Space Treaty[15]

The 1967 Outer Space Treaty prohibits the testing and deployment of nuclear weapons and weapons of mass destruction (WMD) in space and is widely viewed as signifying international opposition to the "militarization of space."[16] While not likely an Army program, some believe ballistic missile defense could be more effective if directed energy-armed satellites were employed instead of current ground and sea-based kinetic ballistic missile defense interceptors.[17] U.S. military reliance on space has a direct effect on a wide variety of Army equities and, therefore, the Army would have a vested interest not only in missile defense but in DE protection of U.S. space-based assets as well.

Should DE weapons become more prevalent on the battlefield and provide those nations who possess them a distinctive and overwhelming military advantage, it is not inconceivable that international efforts to regulate their use might be undertaken.

## How Practical Are DE Weapons?[18]

Although many extol the potential virtues of DE weapons, suggesting they could "change the very nature of warfare" or provide those nations possessing DE weapons an "unchallenged

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[11] Ibid. Article 1.

[12] Discussion Paper "Directed Energy Weapons," Article 36 Discussion Paper for the Convention on Certain Conventional Weapons, Geneva, November 2017, p. 5.

[13] Alane Kochems and Andrew Gudgel, "The Viability of Directed-Energy Weapons," The Heritage Foundation, Washington, D.C., April 28, 2006.

[14] Ibid.

[15] U.S. Department of State, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, https://www.state.gov/t/isn/5181.htm, accessed November 28, 2017.

[16] "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, p. 40.

[17] Ibid.

[18] Information in this section is taken from James Hasik and Julian Eagle-Platon, "The Future of U.S. Laser Weapons," *Real Clear Defense,"* March 14, 2017; Sydney J. Freedberg, Jr., "The Laser Revolution: This Time It May Be Real," *Breaking Defense,* July 28, 2015; and Aaron Mehta, "Kendall Throws Cold Water on Laser Hype," *Defense News,* September 9, 2016.

dominance," others point out that laser-based projects "have over-promised and under-delivered for decades."[19] Along these lines, others have also noted "lasers will save us all-if they ever work," and lasers "have perennially been on the cusp of a major breakthrough."[20] In 2016, Frank Kendall, Under Secretary of Defense for Acquisition, Technology and Logistics (AT&L) from May 2012 until January 2017, reportedly cautioned that DE weapons were not the "panacea" that many believe.[21] Under Secretary of Defense Kendall noted the following:

> There are serious limitations that could make it unlikely that a directed-energy weapon is ever truly effective enough to be used in combat. Those limitations go beyond the long-standing question of how much power such a system would require to be effective, and the hurdles of employing it outside controlled laboratory conditions. There are limitations with lasers because of weather. There are limitations of lasers because of behavior, beams of light in the atmosphere, and the possibility that [an enemy] could harden against them.[22]

Advances made in recent years in solid-state laser technology may challenge this belief. Solid-state lasers are more compact than chemical lasers, which require a significant logistics footprint and employ hazardous chemicals. Solid-state lasers only require electricity to operate but generate a significant amount of heat in weapons-grade lasers. Successfully developing practical cooling technologies for solid-state lasers could potentially further advance their military utility.

# Army Weapons-Related DE Management Architecture[23]

The Deputy Assistant Secretary of the Army for Research and Technology (DASA [R&T]) under the Assistant Secretary of the Army (Acquisitions, Logistics, and Technology (ASA[ALT]) is responsible for oversight of all Army Science and Technology (S&T) investments. Army DE management is broken out as follows:

- Army S&T investments in DE are part of the Lethality Portfolio for ASA(ALT)/DASA (R&T). DE is only one aspect of the Lethality Portfolio, whose major focus areas include fire support, air defense, close combat, and weapons enablers.
- The two major S&T executing commands within the Lethality Portfolio are the Research, Development, and Engineering Command (RDECOM) at Aberdeen Proving Ground, MD, and the Army Space and Missile Defense Command (ASMDC) in Huntsville, AL.
- Falling under RDECOM are the U.S. Army Armament Research, Development and Engineering Center (ARDEC) at Picatinny Arsenal, NJ; the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) in Huntsville, AL; and the U.S. Army Research Laboratory (ARL) in Adelphi, MD.

[19] Freedberg.

[20] Hasik and Eagle-Platon.

[21] Mehta.

[22] Ibid.

[23] Information in this section is taken from a meeting with CRS and Lethality Portfolio Director, Assistant Secretary of the Army (Acquisition, Logistics, and Technology) (ASA (ALT), January 11, 2018.

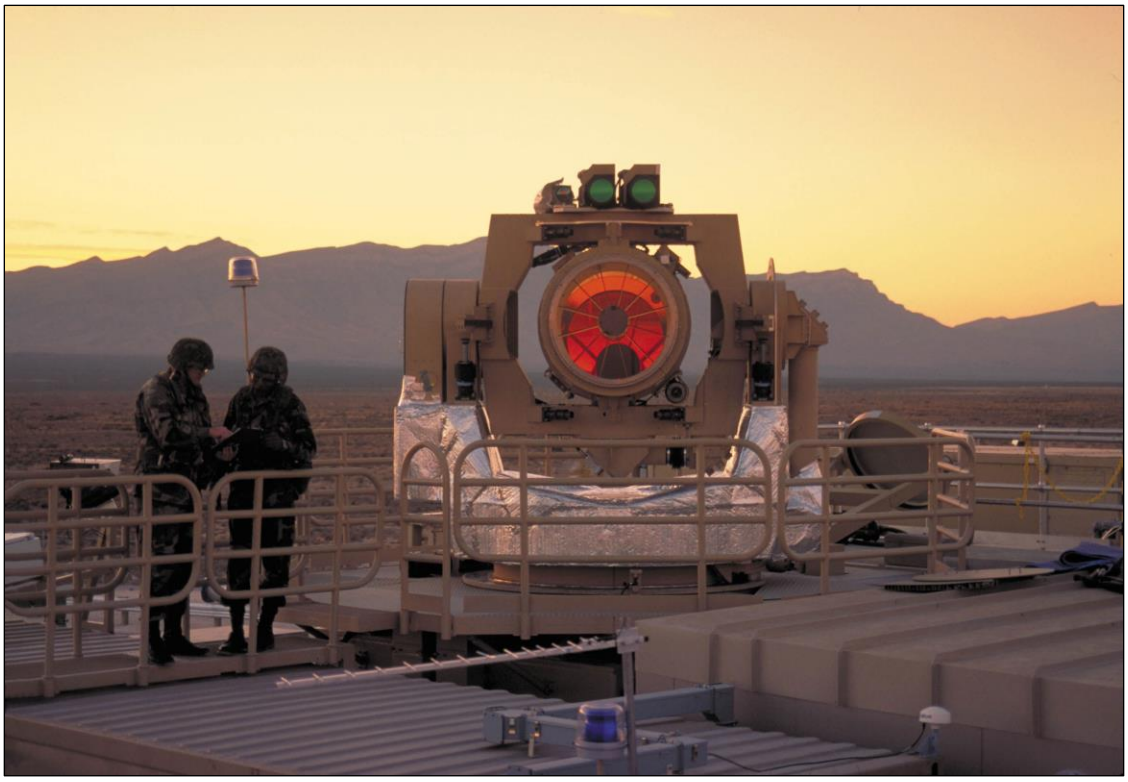
- The Lethality Portfolio Director, ASA (ALT) oversees the portfolio's S&T efforts, coordinates with DOD and the services on DE and other lethality matters, and also interacts with various DOD advanced technology organizations, such as the Defense Advanced Research Projects Agency (DARPA)[24] in Arlington, VA, and the Joint Improvised Threat Defeat Organization (JIDO)[25] at Ft. Belvoir, VA.

# Selected Past Army DE Programs

The following sections provide background information on selected past Army DE programs, some of which are still ongoing. This information is intended to provide historical context for other current programs.

## Tactical High Energy Laser (THEL)[26]

**Figure 2. Tactical High Energy Laser**



**Source:** Northrop Grumman, http://www.northropgrumman.com/MediaResources/Pages/Photo.aspx?pid%3DTA-15003_003%26rel%3D%2F%26name%3DPhotos, accessed November 29, 2017.

Tactical High Energy Laser (THEL) development began in 1996 as a joint U.S.-Israeli program to develop a laser system capable of shooting down Katyusha rockets, artillery, and mortar shells.

[24] https://www.darpa.mil/about-us/about-darpa, accessed January 16, 2018.

[25] https://www.jieddo.mil/, accessed January 16, 2018.

[26] Information in this section is taken from Association of the U.S. Army Background Brief, "Space and Missile Defense Challenges: The Potential of Directed Energy," December 2000; Alane Kochems and Andrew Gudgel, "The Viability of Directed-Energy Weapons," The Heritage Foundation, Washington, D.C., April 28, 2006; and Melissa Olson, "History of Laser Weapon Research," Naval Surface Warfare Center, 2012.

Northrop Grumman was the primary U.S. contractor and several Israeli contractors participated in the program. THEL employed radar to detect and track incoming targets, passing this information to an optical tracking system. A deuterium fluoride (DF) chemical laser would engage targets, causing the incoming rocket or shell to explode short of its intended target.

In 2000 and 2001, THEL shot down 28 Katyusha rockets and 5 artillery shells during operational testing. In August 2004, the system shot down multiple mortar rounds fired both as single rounds and in salvos. In January 2006, after repeated setbacks, cost overruns, and concerns that THEL was too large to be carried on vehicles, the Pentagon cancelled the program.

## Mobile Tactical High Energy Laser (MTHEL)[27]

As an extension of the THEL program, on February 28, 2003, the MTHEL reportedly became a formal acquisition program under the Army's Program Executive Office for Air and Missile Defense. In conjunction with Israel, the goal of the program was to build and test a more mobile and capable version of the THEL by 2008. Northrop Grumman was also the primary U.S. contractor for MTHEL with several Israeli firms also participating. This effort would require dramatically reducing the size and weight of the battle management command, control, and communications system, fire control system, and laser pointer-tracker. As the program progressed, the Army reportedly began to shift its focus from bulky and logistics-intensive chemical lasers to solid-state lasers which could be powered by electricity-producing diesel generators.

## HPM Systems[28]

### Active Denial System[29]

The Active Denial System (ADS) was developed by Raytheon for the U.S. Air Force Research Laboratory and DOD's Joint Non-Lethal Weapons Directorate, with work starting in 2002. The ADS is a nonlethal counterpersonnel weapon that projects a focused millimeter wave energy beam that induces a painful heating sensation on an adversary's skin with the intent of repelling individuals without injury.

In 2010, an Air Force ADS deployed to Afghanistan was withdrawn without having been used. Although no official comment was made at the time, it was speculated that public opposition and fears of possible Taliban propaganda concerning the use of a "radiation weapon" against Afghans might have played a role in this decision.

The Army has explored the development of a Solid State Active Denial Technology or SS-ADT for such missions as crowd dispersal, checkpoint security, perimeter security, and port protection both in fixed and mobile modes (see **Figure 3**). It uses 95 GHz millimeter radio frequency waves,

[27] Information in this section is taken from Inside the Army, "On the Move," March 3, 2003; Emily Hsu, "Army, Israel Pick Northrop Grumman Design for High Energy Laser," *Inside Defense,* August 25, 2003; and Sam Jaffe, "A Congressional Decision to Cut Funding for a Controversial laser Defense Program Developed by Northrop Grumman May Hasten Its Deployment in Iraq," *MIT Technology Review,* May 9, 2005.

[28] Information in this section is taken from John Hudson, "Raytheon Microwave Gun Recalled Amidst Controversy," *The Atlantic,* July 19, 2010; Kevin Robinson-Avila, "The Army is Testing a Microwave Weapon System in the Mountains of New Mexico," *Task & Purpose,* May 21, 2017; and Lauren Poindexter, "ARDEC Engineers Develop Solid State Active Denial Technology for Non-Lethal Crowd Control," U.S. Army, October 12, 2016.

[29] Ibid.

and the Army claims it presents a minimal health risk to its targets and is compliant with treaties and international legal obligations.

## Counter Improvised Explosive Devices (IEDs)

A variety of HPM systems have been developed and fielded to Army units in Iraq and Afghanistan to counter IEDs used to attack vehicle convoys and troops on foot. In May 2017, the Army's Armament, Research, Development, and Engineering Center (ARDEC) reportedly took over the Air Force Research Laboratory's "Max Power" program (see **Figure 4**) designed to destroy IEDs on the battlefield.[30] In 2012, a Max Power prototype was reportedly deployed to Afghanistan for nine months of testing where it was used for 19 combat missions with "convoys across IED-infested roads and highways."[31]

**Figure 3. Prototype Army Active Denial System (ADS)**

**Source:** Lauren Poindexter, "ARDEC Engineers Develop Solid State Active Denial Technology for Non-Lethal Crowd Control, *U.S. Army,* October 12, 2016.

[30] Kevin Robinson-Avila.

[31] Ibid.

**Figure 4. Prototype Max Power System**

**Source:** http://taskandpurpose.com/army-microwave-weapon/, accessed December 1, 2017.

# Selected Current Army DE Initiatives

The Army has a variety of weapons-related DE initiatives underway. The following section provides a brief description of selected unclassified efforts.

## High Energy Laser Tactical Vehicle Demonstrator (HEL TVD) and Multi-Mission HEL (MMHEL)[32]

The High Energy Laser Division of the U.S. Army Space and Missile Defense Command/Army Forces Strategic Command (USASMDC/ARSTRAT) is responsible for developing laser technologies for a number of Army programs. At present, USASMDC is pursuing two paths to develop HEL technologies—the HEL TVD and MMHEL (see **Figure 5** and **Figure 6**).

## High Energy Laser Tactical Vehicle Demonstrator (HEL TVD)

The HEL TVD program involves the development of a 100 kilowatt-class laser to be mounted on an existing Family of Medium Tactical Vehicles (FMTV) truck to provide a counter rocket, artillery, and mortar (C-RAM) capability to protect fixed sites and also provide limited protection in a mobile mode. In addition, the HEL TVD could be adapted in a short-range air defense (SHORAD) role to protect against cruise missiles and UAVs. Current plans call for USASMDC to build the HEL TVD in FY2021 and demonstrate its capabilities and acquire test data in

[32] Information in this section is taken from Kimberley Underwood, "Army Makes a Point of Putting Lasers on Vehicles," *Signal*, December1, 2017; U.S. Army Space and Missile Defense Command, HEL Configurations Summary, May 24, 2017; and U.S. Army Space and Missile Defense Command Briefing, "Multi-Mission High Energy Laser Technology Maturation Initiative," July 19, 2017.

FY2022. If successful, USASMDC would eventually like to transition HEL TVD to a Program of Record.[33]

**Figure 5. Prototype High Energy Laser Tactical Vehicle Demonstrator (HEL TVD)**

**Source:** U.S. Army Space and Missile Defense Command, HEL Configurations Summary, May 24, 2017.

## Multi-Mission High Energy Laser (MMHEL)

The MMHEL program involves integrating a 50 kilowatt-class laser on a Stryker combat vehicle to provide short-range air defense (SHORAD) support to the Army's maneuver brigades. The Army plans to continue development of MMHEL from FY2018 thru FY2021 and transition it to a Program of Record sometime after FY2022.

**Figure 6. Prototype Multi-Mission High Energy Laser (MMHEL)**

**Source:** U.S. Army Space and Missile Defense Command, HEL Configurations Summary, May 24, 2017.

[33] The Defense Acquisition University defines a Program of Record as a program that is funded (approved) across the FYDP, (Future Year Defense Program) through the POM (Program Objective Memorandum). When this occurs, the program becomes a "line item record" in the defense budget, thereby becoming a "program of record." Being designated a Program of Record usually occurs with what is called "Milestone B Approval," when a program is granted "official" status as a developmental program.

## Mobile Experimental High Energy Laser (MEHEL)[34]

The MEHEL is a system that permits experimentation and provides the soldier with hands-on experience operating a HEL mounted on a Stryker combat vehicle (see **Figure 7**). It currently mounts a 5 kilowatt laser and was used in exercises in 2017, where it was able to defeat a number of small rotary and fixed-wing UAVs.

**Figure 7. Mobile Experimental High Energy Laser (MEHEL 2.0)**

**Source:** U.S. Army Space and Missile Defense Command, HEL Configurations Summary, May 24, 2017.

## High Energy Laser Mobile Test Truck (HELMTT)[35]

The HELMTT program involves mounting a 50 kilowatt laser on an existing Heavy Expanded Mobility Tactical Truck (HEMTT) (see **Figure 8**). HELMTT is being used to collect test data that are expected to be used to develop the next generation of HELs and inform future requirements.

**Figure 8. High Energy Laser Mobile Test Truck (HELMTT)**

**Source:** U.S. Army Space and Missile Defense Command, HEL Configurations Summary, May 24, 2017.

[34] U.S. Army Space and Missile Defense Command Briefing, "Mobile Experimental High Energy Laser (MEHEL) Overview," August 16, 2017.

[35] U.S. Army Space and Missile Defense Command, HEL Configurations Summary, May 24, 2017.

## Testing Lasers on Army Helicopters[36]

The U.S. Special Operations Command (USSOCOM) and defense contractor Raytheon reportedly successfully tested an Army AH-64 Apache attack helicopter outfitted with a laser in June 2017, knocking down an unmanned aerial target at a range of 1.4 kilometers. The experiment reportedly was the first time a laser hit a target from a rotary-wing aircraft. While project officials note they are not at the point where they can put forward a business case to advance the project, they are using this test to better understand the interactions between the aircraft, the laser, and the target.

## Lasers on Next-Generation Army Combat Vehicles?[37]

Army officials suggest their next generation combat vehicle could feature an active protection system employing DE to protect the vehicle as well as a laser weapon which could replace traditional mounted weapons.[38] The Army asserts active protection systems featuring lasers could provide 360-degree protection from incoming rounds or UAVs, and laser weapons might also be used to disable or possibly destroy enemy vehicles. Officials note that in order to begin fielding Army units with a next-generation combat vehicle in 2035, major decisions will need to be made by 2025, suggesting that the Army has about seven years to advance laser weapons technology to a point where it can be considered a viable option for incorporation into the next-generation combat vehicle.

# Overview of Selected Foreign DE Weapons Efforts

Other nations are developing DE weapons for a variety of applications. The following sections provide a brief overview of reported DE weapons-related efforts in Russia, China, and Israel and are intended to provide policymakers with a point of comparative reference when examining U.S. programs. Weapons-related DE efforts are not limited to these three countries.

## Russia[39]

The Soviet Union reportedly began experimenting with lasers in the 1950s and 1960s. In the 1970s, they developed fixed ground-based systems intended to destroy ballistic missiles in their terminal descent phase. After the 1972 Anti-Ballistic Missile Treaty, the Soviets attempted to reorient these systems to damage orbiting satellites but were unsuccessful due to inaccurate tracking systems. During the Cold War, the Soviets also experimented with mounting lasers on tanks, primarily intended to blind the superior optics and targeting systems on NATO tanks.

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[36] Information in this section is taken from Jared Keller, "The Army Just Test-Fired a Frickin' Laser beam from an Apache Attack Helicopter," *Task and Purpose,* June 26, 2017 and Leigh Giangreco, "U.S. Army Eyes Laser Addition for Rotorcraft Fleet," *Flight Global,* October 11, 2017.

[37] Information in this section is taken from 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.

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

[39] Information in this section is taken from Sebastien Roblin, "Russia's Cold War Super Weapon (Put Lasers on Everything it Can)," *The National Interest,* July 16, 2017; John Keller, "New Russian Directed-Energy Weapon Could Complicate U.S. Military Strategic Planning," *Military & Aerospace Electronics,* July 7, 2015; Michael Peck, "Russia's Next Military Game Changer: Micro Wave Weapons," *The National Interest,* July 12, 2016; and Damien Sharkov, "Russian Military Plans Missile Killing Laser for Next-Generation Warplane. Does it Work?," *Newsweek,* July 27, 2017.

Another version, mounted on the chassis of an antiaircraft vehicle, was said to be able to destroy the optics on hostile aircraft as far as 8 to 10 kilometers away.

At present, Russia is reportedly developing a DE weapon capable of destroying guidance and navigation systems in manned and unmanned aircraft and precision-guided missiles. Russia also claims this weapon can disrupt Global Positioning System (GPS) navigation signals and destroy radio communications equipment and satellites. This weapon supposedly can be mounted on vehicles, ships, and aircraft. Beyond these claims, little is publically known about this purported DE weapon. Reports also suggest Russia currently has laser systems for aircraft and helicopter defense and plans to mount lasers with greater attack capabilities on their sixth-generation aircraft, which are not likely to be operational until the late 2030s. The Russians are reportedly also planning to arm unmanned aerial vehicles (UAVs) with HPMs, including hypersonic UAVs supposedly in development.

Although it is difficult to predict how successful these Russian efforts might be, these systems "could complicate U.S. military strategic planning, which for the past quarter-century has relied heavily on precision-guide munitions, GPS navigation, and battlefield tactical networking."[40]

## China[41]

Chinese development of laser technology reportedly dates back to the early 1960s. Some Chinese military experts believe DE weapons will become more prevalent over the next 10 to 20 years and could dominate the battlefield in 30 years. In 2015, the Chinese book *Light War* or *Light Warfare,* published by the People's Liberation Army (PLA) Press, emphasized a concept referred to as "Informatization." This concept suggests the Chinese believe the "next phase [of warfare] will be characterized by combining manipulations of 'Big Data' and increasing autonomy/artificial intelligence, with directed energy weapons at the core."[42] As part of this concept, emphasis is placed on autonomous space-based laser weapons. China's evolving space program and continued work on airborne lasers suggests China is actively seeking to field a space-based laser.

In September 2006, China reportedly used ground-based lasers to "dazzle" or blind U.S. surveillance satellites. In 2016, China reportedly exhibited its 30 kilowatt Low-Altitude Laser Defending System (LASS) that it claimed was capable of a 4-kilometer range and was useful for defeating swarms of small plastic drones. On November 28, 2017, China's Ministry of National Defense reportedly released a video of the test firing of what is believed to be a new laser-based air defense weapon designed to defeat unmanned aerial systems.[43] China is also believed to be developing naval lasers, suggesting the PLA Navy's Type-055 next-generation cruiser could eventually employ a laser weapon.

In 2014, China reportedly introduced its WB-1 microwave active-denial system, similar to the U.S. Active Denial System. In 2017, China reportedly achieved "unexpected success in their

[40] Keller.

[41] Information in this section is taken from Richard D. Fisher Jr., "China's Progress with Directed Energy Weapons," Testimony before the U.S.-China Economic and Security Review Commission, Washington, D.C., February 23, 2017 and Elsa B. Kania, "The PLA's Potential Breakthrough in High-Power Microwave Weapons," *The Diplomat*, March 11, 2017.

[42] Richard D. Fisher Jr.

[43] Gabriel Dominguez and Neil Gibson, "China Tests Laser-Based Counter UAS System," Jane's Defence Weekly, December 6, 2017.

development of a high-power microwave (HPM) weapon."[44] If this alleged unspecified HPM breakthrough is successfully developed as a ship-borne antimissile system or employed as part of China's air defense systems it is speculated that

> Potentially, such a weapon system would undermine the efficacy of even the most advanced U.S. missiles, such as the Long Range Anti-Ship Missile (LRASM) currently under development. Its likely applications could also include its use as an anti-satellite (ASAT) weapon or incorporation with missiles in order to overcome enemy air defenses. Once operationalized, this new weapon could thus contribute to China's anti-access/area-denial (A2/AD) capabilities.[45]

Some believe China is diligently working to dominate what they see as the next phase of warfare, not so much driven by a fear that the United States has it at a defensive disadvantage, but more along the lines of achieving a geostrategic advantage over other nations. It is also suggested that any military advantage the United States seeks from developing DE weapons could be short-lived given the possibility that China already has an active space-based laser antisatellite program and is developing HEL and HPM weapons that could enter service by the end of the decade.[46]

### Israel[47]

The Israeli Defense Force (IDF) reportedly first employed lasers for target designation and range finding during the first Lebanon War in 1982. Lasers were also used for guided munitions. Israel's primary laser program, called the Nautilus program, started in 1996 when Israel began cooperative efforts with the United States to develop a laser system capable of shooting down Katyusha rockets, artillery, and mortar shells. In 2006, when the Pentagon cancelled the program, the Israelis began the Iron Dome program, which employed interceptor rockets in lieu of lasers to shoot down incoming rockets, artillery, and mortar rounds.

Israel reportedly claims that Iron Dome has been successful in intercepting 90% of attacks, but at 100,000 U.S. dollars per interceptor, this is viewed by some as an expensive capability. In early 2014, Israel reportedly initiated its Iron Beam program, designed to use a high-kilowatt laser to destroy short-range rockets, artillery, mortars, and UAVs. The intent is to employ Iron Beam with Iron Dome. It is unknown when the IDF plans to deploy Iron Beam.

## Potential Issues for Congress

### What Progress Has Been Made on Army Weapons-Related HPM Programs?

Although information on Army HEL programs is publically available through a variety of sources, a similar level of public programmatic detail does not appear to be available for Army weapons-related HPM programs or efforts. The Lethality Portfolio Director, ASA (ALT) noted that effective in FY2018, it divested itself of HPM S&T and rebalanced to focus on peer and near-

[44] Elsa B. Kania.

[45] Ibid.

[46] Harsh Vasani, "How China is Weaponizing Outer Space," The Diplomat, January 19, 2017.

[47] Information in this section is taken from Dani Asher, "U.S. Military Presents: The Return of the Laser," *Israel Defense,* September 3, 2017 and Joshua A. Krisch, "Israel Wants to Use Lasers to Shoot Down Missiles," *Popular Mechanics,* February 18, 2014.

peer threats and Army modernization priority areas of long-range precision fires and air and missile defense.[48]

A greater understanding of the Army's HPM initiatives could potentially benefit Congress in its oversight and authorization and appropriations roles. According to the Army, the Joint Nonlethal Weapons Directorate, the Navy and Air Force, and industry maintain investments in HPM technologies, which the Army can leverage for programs if required. In this regard, are there currently any HPM programs at the joint or service level or in industry that are presently under consideration by the Army? Other services are actively involved in HPM development, such as the Air Force's Counter-Electronics High Power Microwave Advanced Missile Project (CHAMPS).[49] The CHAMPS system reportedly can be fitted into an air-launched cruise missile (ALCM) which can fly into enemy airspace at low altitude and emit microwave energy to disable electronic systems. Although reportedly not yet operational, CHAMP has been touted by some as a possible response to North Korea's ballistic missiles.

A similar understanding of the Army's HPM intentions, either at the classified or unclassified level, could potentially be useful for policymakers to determine if the Army is taking full advantage of HPM technologies and if related efforts warrant future investment.

## How Do U.S. Army DE Efforts Compare to Our Allies and Potential Adversaries?

The U.S. military does not enjoy an exclusive monopoly on DE weapons development: both allies and potential adversaries are developing HEL and HPM systems for their ground forces. In particular, it is not unreasonable to expect other countries will seek to deploy operational DE systems in the near future that potentially could rival or surpass similar U.S. systems under development. Should this become the case, there are some potential issues Congress might choose to examine. Some possible questions include the following:

- Are potential adversary DE weapon systems inferior, comparable, or superior to U.S. systems under development?
- If potential adversaries deploy effective DE weapons systems, how might this affect the U.S. military's ability to conduct operations at the strategic, operational, and tactical level—particularly in the ground combat domain?
- Will an enemy with DE weapons pose an insurmountable antiaccess/area denial (A2/AD) challenge to U.S. ground forces in all phases of combat operations?
- How will potential adversary DE weapon systems affect U.S. Army modernization including the need for additional resources?

[48] Information in this section is taken from a meeting with CRS and Lethality Portfolio Director, Assistant Secretary of the Army (Acquisition, Logistics, and Technology) (ASA (ALT), January 11, 2018.

[49] Information in this section is taken from Cynthia McFadden, William M. Arkin, Kevin Monahan, and Kenzi Abou-Sabe, " "Microwave Weapon Could Fry North Korean Missile Controls, Say Experts," *NBCNews.com,* December 7, 2017.

## How Close Is the Army to Fielding Operational DE Weapon Systems?

Army officials have noted a number of successful concept demonstrations of DE systems including participation in exercises such as Maneuver Fires Integration Experiments (MFIX) in 2016 and 2017 and the Joint Improvised Threat Defeat Organization (JIDO) Hard-Kill Challenge.[50] If the Army can continue to successfully develop the integration of higher-power lasers on a variety of ground vehicles, it plans to transition these technologies to a Program of Record to develop operational mobile SHORAD/C-RAM capabilities sometime after FY2022.[51] Although this provides policymakers a date for planning purposes, being designated a Program of Record can be viewed as a programmatic "entry point"; subsequent development, testing, selecting a vendor(s), and fielding such a system would take considerably longer, which raises a number of potential questions:

- Assuming the Army is successful in transitioning current HEL developmental efforts into a Program of Record sometime after FY2022 and funding is available, when does it anticipate fielding these systems to the operational force?
- Although fielding of these systems maybe a decade or more off, how does the Army envision employing these systems to their best effect? Will they be used to defend critical static targets or will they be able to accompany maneuver forces?
- Has the Army begun to develop tactics, techniques, and procedures for these systems, perhaps based on past and future exercise participation?
- Will the Army develop specific units (platoons, companies, or battalions) of these DE weapon systems or will they be integrated into existing formations?
- Will the deployment of DE weapon systems into the operational force result in phasing out or retiring legacy systems?

## How Practical Are These Systems Given Their Constraints?

Although many experts and defense officials have extolled the potential virtues of DE weapons, others contend there are some significant constraints and developmental challenges associated with these weapons. Given this debate, it appears reasonable to question the practicality of ground-based DE weapons—will they be a "novelty" or will they have a discernable tactical and operational impact?

Some of the constraints and challenges include the ability to generate sufficient power; how to sufficiently cool HEL systems; how to overcome DE attenuation due to terrain, weather, and/or obscurants; the lack of an indirect fire capability; and current limited ranges of HEL systems. Other challenges include the potential susceptibility of DE systems to relatively simple or inexpensive countermeasures as well as how to prevent collateral damage to U.S. systems when certain types of DE weapons are employed against enemy targets. Another potential issue is if future Army DE weapons could have the capability to destroy enemy ground combat vehicles and aircraft—and not just simply interfere with or disable or destroy electronic subsystems that could be easily replaced, permitting the vehicle or aircraft to be returned to service. Such a capability could have significant future operational, logistical, and resource implications for the Army.

[50] U.S. Army Space and Missile Defense Command Briefing, "Mobile Experimental High Energy Laser (MEHEL) Overview," August 16, 2017.

[51] Ibid.

## The Army's New Modernization Command and Management of Weapons-Related DE Programs.[52]

In October 2017, Acting Secretary of the Army Ryan D. McCarthy established a task force to examine the consolidation of the Army's modernization process under one roof and ultimately establish a new Army Modernization Command. Part of this task force's activities includes reviewing the potential reallocation of functions from existing commands and agencies, taking into consideration statutory constraints that currently restrict the reassignment of certain functions outside the secretariat and, in some cases, outside a specific Assistant Secretary of the Army.[53] The Army reportedly plans to stand up this new command in the summer of 2018.

The Army's plan to establish a new Modernization Command suggests possible oversight considerations for Congress:

- Would the Army's DE portfolio be subject to reassignment or possibly disestablishment under the Army's modernization review?
- Would weapons-related DE efforts receive more or less emphasis and possibly resources under a new Army Modernization Command?
- Would current Lethality Portfolio focus areas—fire support, air defense, close combat, and weapons enablers—be reallocated under a new Army Modernization Command, and how might this affect ongoing and planned Army HEL efforts?
- How would current organizations that conduct Lethality Portfolio efforts—the Research, Development, and Engineering Command (RDECOM), the U.S. Army Space and Missile Defense Command (USASMDC), the U.S. Army Armament Research, Development and Engineering Center (ARDEC), the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC), and the U.S. Army Research Laboratory (ARL)—be affected by the establishment of a new Army Modernization Command?

## What Are the Estimates of Resources Needed to Fund the Army's Full Suite of DE Systems?

With Army weapons-related DE efforts progressing toward becoming programs of record, there is an expectation that they could potentially play a role in future force protection, counter rocket, artillery, and mortar (C-RAM), and short-ranged air defense (SHORAD) operations. If these programs prove successful, the next logical step would seem to be developing detailed requirements over and above those associated with the fielding of an individual weapon system. Possible oversight questions include the following:

- How many total systems does the Army plan to acquire, and will they be incorporated into existing units as individual systems or will entire units of new DE systems be established?

[52] Information in this section is taken from Secretary of the Army Memorandum "Army Directive 2017-33 (Enabling the Army Modernization Task Force)," November 7, 2017; Jen Judson, "Army's Modernization Command Taking Shape Under Freshly Picked Leaders," *Defense News,* November 6, 2017; and Courtney McBride, "New Memo Details Efforts to Fundamentally Alter Army Modernization." *InsideDefense.com,* November 15, 2017.

[53] Ibid.

- What are the manning, equipping, basing, and training requirements associated with potential new DE weapon systems and units?

By developing comprehensive resource requirements for the Army's full suite of DE weapon systems, a total program cost—sometimes referred to by the Army as the DOTLMPF cost (doctrine, organizations, training, leader development, material, personnel, and facilities)—can be established, which could aid policymakers in making enterprise-level decisions about Army capabilities, modernization, force structure, and resource allocation.

# Selected FY2018 Army DE Funding

A comprehensive funding profile of all unclassified Army DE-related programs was not available to CRS, but the U.S. Army Space and Missile Defense Command/Army Forces Strategic Command (USASMDC/ARSTRAT) provided CRS with some programmatic funding information that provides useful context when evaluating these programs (see **Table 1**). The Lethality Portfolio Director, ASA (ALT) noted the Army divested itself of HPM in S&T beginning in FY2018 and focuses more on peer and near-peer threats and Army modernization priority areas of long-range precision fires[54] and air and missile defense.[55]

**Table 1. Selected FY2018 Programs: Budget Request, Authorizations, Appropriations, and Program Objective Memorandum (POM) Amounts**

All Figures in Millions

| Program Element (PE) | FY18 Budget Request | FY18 National Defense Authorization Act | FY18 Defense Appropriations Act | FY19 POM | FY20 POM | FY21 POM | FY22 POM |
|---|---|---|---|---|---|---|---|
| HEL Technology | $22.785 | $22.785 | $32.785 (+$10.000) | $29.502 | $24.457 | $26.190 | $26.780 |
| HEL Technology Demonstration | $24.096 | $24.096 | $39.096 (+$15.000) | $26.253 | $30.169 | $30.035 | $30.736 |
| Multi-Mission HEL (MMHEL) | $82.000 | $82.000 | $82.000 | — | — | — | — |
| In House Laboratory Independent Research | $.941 | $.941 | $.941 | $.959 | $979 | $.999 | $1.020 |

**Sources:** Department of Defense Fiscal Year (FY) 2018 Budget Estimates, May 2017; H.Rept. 115-404, National Defense Authorization Act for Fiscal Year 2018, Conference Report to Accompany H.R. 2810, November 9, 2017; and H.Rept. 115-219, Department of Defense Appropriations Bill, Report of the Committee on Appropriations to Accompany H.R. 3219, July 13, 2017.

[54] In this context, long-range precision fire refers to the Army's ability to deliver precise artillery and missile attacks over an extended range.

[55] Information in this section is taken from a meeting with CRS and Lethality Portfolio Director, Assistant Secretary of the Army (Acquisition, Logistics, and Technology) (ASA (ALT), January 11, 2018.

# Congress and Army DE Programs

Congress has played a role in the furtherance of DOD and Army DE efforts. The FY2017 National Defense Authorization Act (P.L. 114-328) called for the following:

> **SEC. 219. DESIGNATION OF DEPARTMENT OF DEFENSE SENIOR OFFICIAL WITH PRINCIPAL RESPONSIBILITY FOR DIRECTED ENERGY WEAPONS.**
>
> (a) DESIGNATION OF SENIOR OFFICIAL
>
> (1) IN GENERAL. Not later than 180 days after the date of the enactment of this Act, the Secretary of Defense shall designate a senior official already serving within the Department of Defense as the official with principal responsibility for the development and demonstration of directed energy weapons for the Department.
>
> (2) DEVELOPMENT OF STRATEGIC PLAN.
>
> (A) IN GENERAL. The senior official designated under paragraph (1) shall develop a detailed strategic plan to develop, mature, and transition directed energy technologies to acquisition programs of record.
>
> (B) ROADMAP. Such strategic plan shall include a strategic roadmap for the development and fielding of directed energy weapons and key enabling capabilities for the Department, identifying and coordinating efforts across military departments to achieve overall joint mission effectiveness.
>
> (3) ACCELERATION OF DEVELOPMENT AND FIELDING OF DIRECTED ENERGY WEAPONS CAPABILITIES
>
> (A) IN GENERAL. To the degree practicable, the senior official designated under paragraph (1) shall use the flexibility of the policies of the Department in effect on the day before the date of the enactment of this Act, or any successor policies, to accelerate the development and fielding of directed energy capabilities.
>
> (B) ENGAGEMENT. The Secretary shall use the flexibility of the policies of the Department in effect on the day before the date of the enactment of this Act, or any successor policies, to ensure engagement with defense and private industries, research universities, and unaffiliated, nonprofit research institutions.
>
> (4) ADVICE FOR EXERCISES AND DEMONSTRATIONS. The senior official designated under paragraph (1) shall, to the degree practicable, provide technical advice and support to entities in the Department of Defense and the military departments conducting exercises or demonstrations with the purpose of improving the capabilities of or operational viability of technical capabilities supporting directed energy weapons, including supporting military utility assessments of the relevant cost and benefits of directed energy weapon systems.
>
> (5) SUPPORT FOR DEVELOPMENT OF REQUIREMENTS. The senior official designated under paragraph (1) shall coordinate with the military departments, Defense Agencies, and the Joint Directed Energy Transition Office to define requirements for directed energy capabilities that address the highest priority warfighting capability gaps of the Department.
>
> (6) AVAILABILITY OF INFORMATION. The Secretary of Defense shall ensure that the senior official designated under paragraph (1) has access to such information on programs and activities of the military departments and other defense agencies as the Secretary considers appropriate to coordinate departmental directed energy efforts.
>
> (b) JOINT DIRECTED ENERGY TRANSITION OFFICE.

> (1) REDESIGNATION. The High Energy Laser Joint Technology Office of the Department of Defense is hereby redesignated as the ''Joint Directed Energy Transition Office'' (in this subsection referred to as the ''Office''), and shall report to the official designated under subsection (a)(1).
>
> (2) ADDITIONAL FUNCTIONS. In addition to the functions and duties of the Office in effect on the day before the date of the enactment of this Act, the Office shall assist the senior official designated under paragraph (1) of subsection (a) in carrying out paragraphs (2) through (5) of such subsection.
>
> (3) FUNDING. The Secretary may make available such funds to the Office for basic research, applied research, advanced technology development, prototyping, studies and analyses, and organizational support as the Secretary considers appropriate to support the efficient and effective development of directed energy systems and technologies and transition of those systems and technologies into acquisition programs or operational use.[56]

On January 23, 2017, the Congressional Directed Energy Caucus wrote to Secretary of Defense Mattis asking, among other things

> To quickly implement Section 219 of the fiscal year 2017 National Defense Authorization Act, Public Law No: 114-328, by designating a senior official to have principal responsibility for the development and demonstration of directed energy weapon systems throughout the Department. Currently, the technical requirements for various service and agency directed energy programs vary broadly, which results in the pursuit of different technical approaches, a valid risk reduction strategy for directed energy across the Department. The aforementioned designated senior official will be critical to the development of the required strategic plan and roadmap for accelerating the development of this technology toward acquisition programs of record.[57]

The FY2018 National Defense Authorization Act (P.L. 115-91) calls for the following:

> **SEC. 215. DEPARTMENT OF DEFENSE DIRECTED ENERGY WEAPON SYSTEM PROTOTYPING AND DEMONSTRATION PROGRAM.**
>
> (a) DESIGNATION OF UNDER SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING AS THE OFFICIAL WITH PRINCIPAL RESPONSIBILITY FOR DEVELOPMENT AND DEMONSTRATION OF DIRECTED ENERGY WEAPONS.
>
> Subsection (a)(1) of section 219 of the National Defense Authorization Act for Fiscal Year 2017 (Public Law 114–328; 10 U.S.C. 2431 note) is amended by striking ''Not later'' and all that follows through ''Department of Defense'' and inserting ''The Under Secretary of Defense for Research and Engineering shall serve''.
>
> (b) PROTOTYPING AND DEMONSTRATION PROGRAM. Such section is further amended by adding at the end the following new subsection:
>
> (c) PROTOTYPING AND DEMONSTRATION PROGRAM.
>
> (1) ESTABLISHMENT. The Secretary of Defense, acting through the Under Secretary, shall establish a program on the prototyping and demonstration of directed energy weapon systems to build and maintain the military superiority of the United States by:
>
> (A) accelerating, when feasible, the fielding of directed energy weapon prototypes that would help counter technological advantages of potential adversaries of the United States; and (B) supporting the military departments, the combatant commanders, and other

[56] P.L. 114-328, National Defense Authorization Act for Fiscal Year 2017, December 23, 2016.

[57] Letter from Sen. Martin Heinrich, Rep. Doug Lamborn, and Rep. James R. Langevin to Secretary of Defense James Mattis, January 23, 2017.

relevant defense agencies and entities in developing prototypes and demonstrating operational utility of high energy lasers and high powered microwave weapon systems.

(2) GUIDELINES. (A) Not later than 180 days after the date of the enactment of the National Defense Authorization Act for Fiscal Year 2018, the Under Secretary shall issue guidelines for the operation of the program established under paragraph (1), including the following:

(i) Criteria required for an application for funding by a military department, defense agency or entity, or a combatant command.

(ii) The priorities, based on validated requirements or capability gaps, for fielding prototype directed energy weapon system technologies developed by research funding of the Department or industry.

(iii) Criteria for evaluation of an application for funding or changes to policies or acquisition and business practices by such a department, agency, or command for purposes of improving the effectiveness and efficiency of the program.

(B) Funding for a military department, defense agency, or combatant command under the program established under paragraph (1) may only be available for advanced technology development, prototyping, and demonstrations in which the Department of Defense maintains management of the technical baseline and a primary emphasis on technology transition and evaluating military utility to enhance the likelihood that the particular directed energy weapon system will meet the Department end user's need.

(3) APPLICATIONS FOR FUNDING.—(A) Not less frequently than once each year, the Under Secretary shall solicit from the heads of the military departments, the defense agencies, and the combatant commands applications for funding under the program established under paragraph (1) to be used to enter into contracts, cooperative agreements, or other transaction agreements entered into pursuant to section 2371b of title 10, United States Code, with appropriate entities for the prototyping or commercialization of technologies.

(B) Nothing in this section shall be construed to require any official of the Department of Defense to provide funding under the program to any congressional earmark as defined pursuant to clause 9 of rule XXI of the Rules of the House of Representatives or any congressionally directed spending item as defined pursuant to paragraph 5 of rule XLIV of the Standing Rules of the Senate.

(4) FUNDING. (A) Except as provided in subparagraph (B) and subject to the availability of appropriations for such purpose, of the funds authorized to be appropriated by the National Defense Authorization Act for Fiscal Year 2018 or otherwise made available for fiscal year 2018 for research, development, test, and evaluation, defense-wide, up to $100,000,000 may be available to the Under Secretary to allocate to the military departments, the defense agencies, and the combatant commands to carry out the program established under paragraph (1).

(B) Not more than half of the amounts made available under subparagraph (A) may be allocated as described in such paragraph until the Under Secretary:

(i) develops the strategic plan required by subsection (a)(2)(A); and

(ii) submits such strategic plan to the congressional defense committees.

(5) UNDER SECRETARY DEFINED.—In this subsection, the term 'Under Secretary' means the Under Secretary of Defense for Research and Engineering in the Under

> Secretary's capacity as the official with principal responsibility for the development and demonstration of directed energy weapons pursuant to subsection (a)(1).[58]

While these FY2017 and FY2018 legislative provisions address DOD specifically, they carry implications for Army DE programs. These provisions addressing the designation of a senior DOD official to be responsible for all DE efforts; the formulation of a DOD DE strategy and roadmap; the acceleration of developmental and fielding activities; and establishment of a DE prototyping and demonstration program suggest potential congressional concern with overall DOD management of its DE activities. As such, the Army, as well as the other services, will likely be affected by the implementation of these provisions and may have to either develop or modify their respective management approaches to DE weapons.

[58] P.L. 115-91, National Defense Authorization Act for Fiscal Year 2018, December 12, 2016.

# Appendix A. Types of DE Weapons

## High Energy Lasers (HELs)

From the Center for Strategic and Budgetary Assessments (CSBA) 2012, "Changing the Game: The Promise of Directed-Energy Weapons,"

> In contrast to light bulbs that emit "white light" (photons with a multitude of different wavelengths and phases in all directions), lasers produce narrow beams of monochromatic (single-wavelength) light in coherent beams (all photons traveling in the same direction with the same phase). These narrow beams can focus energy precisely on a designated point. There are three primary types of HELs: **chemical lasers**; **solid-state lasers**; and **free electron lasers**. Beyond differences in the lasing media, each type has fundamental attributes that affect their ability to mature into operational weapon systems. In addition to the actual lasers, target tracking, laser pointing, thermal management, and beam control systems are required to place as much laser energy as possible on a target over operationally relevant distances.[59]

## Chemical Lasers

From CSBA:

> Chemical lasers are the only current DE systems able to achieve the power needed to interdict targets such as ballistic missiles over hundreds of kilometers. As a result, chemical lasers have until recently been the basis for DOD's most mature HEL concepts. Chemical lasers use exothermic (energy-liberating) reactions of various chemicals in the gas phase to create atoms or ions in excited states within a lasing medium. Since these reactions must occur at very low pressures—typically only a couple percent of atmospheric pressure—chemical lasers are large devices requiring vacuum pumps, complex chemical management systems, and low-pressure reaction chambers contained inside a laser resonator.[60]

## Solid-State Lasers (SSLs)

From CSBA:

> The first laser invented in 1960 was an SSL. Today, low-power SSLs with outputs of milliwatts are used in a wide variety of consumer products, such as DVD players and laser jet printers. Watt-class SSLs are used in numerous military applications, including target range finders (laser radars, also known as ladars), imagers, target designators, and DOD's Large Aircraft Infrared Countermeasure (LAIRCM) defensive system. SSLs use ceramic or glass-like solids, rather than a gas, as their lasing media.[61]

## Free Electron Lasers (FELs)

From CSBA:

> Free electron laser (FEL) systems accelerate beams of electrons to nearly the speed of light in racetrack-like accelerator rings and use powerful magnets to "wiggle" the electron

[59] Mark Gunzinger and Chris Dougherty, "Changing the Game: The Promise of Directed-Energy Weapons," Center for Strategic and Budgetary Assessments (CSBA), 2012, pp. 27-28.

[60] Ibid., pp. 28-29.

[61] Ibid., pp. 32-33.

> beams to generate high-energy beams of laser photons. FELs are of interest to the Navy due to their potential to achieve the high power outputs needed to interdict hardened targets such as incoming ballistic missile reentry vehicles, and their unique ability to "tune" their beams to different wavelengths to different wavelengths so they can better transmit through the dense, humid atmospheres of maritime environments. Current developmental FELs are extremely large and inefficient.[62]

## High Powered Microwaves (HPMs)

From CSBA:

> A high-power microwave weapon uses electricity to power a microwave generator that emits very short pulses—typically nanoseconds to microseconds in duration—of microwave radiation at megawatt to gigawatt output levels. Future HPM weapons could emit beams of radiation that are a few degrees wide to attack targets in specific locations or emit radiation multi-directionally to degrade electronic components over wider areas. The effects created by HPM applications could range from temporarily disrupting electronic systems such as computers to physically burning out systems that are not shielded against the high electromagnetic fields generated by an HPM pulse. Since HPM beams cannot be as tightly focused as lasers, the energy per unit area in HPM beams decreases significantly over distance. This could impose significant operational limitations compared to longer-range laser weapons. Since HPM weapons would affect all unshielded electronic systems within their beam spots, care must be taken when employing them to avoid collateral damage to nearby friendly systems.[63]

It can be argued that HPM weapons are not "true" DE weapons but they are treated as such by DOD.

> Radio-frequency weapons propagate intense bursts of energy at microwave or lower frequencies that disable or destroy electronics. Such bursts can be generated by both nuclear and conventional explosives, but since these mechanisms result in omnidirectional, wideband releases of energy, they cannot properly be called "directed" energy. Radio-frequency devices producing directed energy would typically resemble radar transmitters, with steerable antennas for aiming their beams. It could be argued that radio-frequency weapons transmitting omnidirectionally but on tightly restricted frequencies are a form of directed energy.[64]

Some, however, question the viability of HPM weapons.[65] Moisture in the air absorbs microwaves, and uncertainty on how electromagnetic energy flows through structures makes it difficult to predict what kind of damage an HPM weapon could do. In addition, countermeasures to HPM weapons could be as simple as surrounding sensitive electronics with a Faraday cage.[66] Further compounding this is the classified nature of most of DOD's HPM programs, which makes public and academic examination of these programs problematic.

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[62] Ibid., pp. 36-37.

[63] Ibid., pp. 38-39.

[64] "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, p. 6.

[65] Information in this section is taken from Sharon Weinberger, "High-Power Microwave Weapons Start to Look Like Dead-End," *Scientific American,* September 12, 2012.

[66] A Faraday cage is a metallic structure that distributes charges or radiation around the cage's exterior, canceling out electric charges or radiation within the cage's interior. A shortcoming of Faraday cages is that they also can prevent or restrict FM transmissions and outgoing transmissions.

# Appendix B. Background

## How They Work

### HELs

From the Lexington Institute:

> Although there are several different methods by which high-energy lasing can be accomplished, the generic components of a laser weapon are always the same. There must be a power source with adequate fuel; there must be a chamber in which coherent light is generated; there must be optical mechanisms for forming and focusing a beam; there must be sensors for tracking intended targets and characterizing the space between the laser and the targets; there must be beam-control techniques for shaping the beam and directing it so it traverses the intervening space with maximum efficiency; and there must be some method of assessing whether the energy deposited on the target has had the desired effect.
>
> Assuming a specific degree of pointing accuracy, the lethality of the laser against any class of targets will be determined by power level, wavelength and optical dimensions. These factors are typically traded off in designing an integrated system. Shorter wavelength enables designers to use less power or smaller optical dimensions and still achieve desired lethality, although the effects of atmospheric turbulence are more pronounced at shorter wavelengths. Higher power or larger optics enables the same effect to be achieved at longer wavelengths with less degradation from turbulence. However, there are limits on each of these parameters dictated by physical laws. For example, a laser operating at any given wavelength in the atmosphere will have a "critical power level" that defines its maximum lethality; at higher power levels, beam degradation resulting from interaction with the atmosphere will actually diminish energy deposited on the target. High power output can also exceed the tolerances of optical systems, leading to system failure.[67]

### HPMs

From the Lexington Institute:

> The one significant offensive application of directed energy likely to be available in the near-term is the high-power microwave "bomb" (HPM). Such a weapon, in which detonation of an explosive charge creates a pulsed-power source to drive the HPM generator, could play a role in the disruption and even destruction of a wide range of electronic systems. HPM weapons have very interesting operational characteristics. First, an HPM weapon is an area weapon, whose area of effect is determined by the frequency generated, the area of view of the antenna and the power of the pulse generator. Second, all targets within the area of effect will be attacked simultaneously (because HPMs can generate an electrical pulse over a wide area they can be used effectively against imprecisely located targets). Third, they can achieve a "system kill" by damage inflicted upon electronic circuits, components, and subsystems. Fourth, HPM's are effective against electronics even when those systems are turned off. Fifth, the only effective defense is to completely isolate the target from means of conducting energy—a step that would in all likelihood produce a mission kill. Sixth, because they use an electromagnetic pulse that can affect electronic systems from a distance, HPM weapons offer the prospect of reduced

[67] "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, p. 8.

collateral damage. Finally, HPM weapons are inherently tunable, allowing the user to graduate the effects imposed on the target.[68]

## Types of Army Weapons—Related Applications

Common military uses for DE include detection, targeting, range-finding, medical treatment, and communications. There are a variety of weapons-related applications for HELs and HPMs, and if these technologies improve and become more practical for military use, new applications may likely be identified. The following are some of the weapons-related applications that have been or are currently being pursued:

### HELs

- Ground-based defense against rockets, artillery, and mortars (referred to as Counter Rockets, Artillery, and Mortars or C-RAM);
- Ground-based defense against unmanned aerial vehicles (UAV), rotary wing, fixed-range aircraft, cruise missiles;
- Airborne defense against Man-Portable Air Defense Systems (MANPADS); and
- Force protection.

### HPMs

- Area denial;
- Vehicle-mounted defeat of Improvised Explosive Devices (IEDs);
- Ground-based vehicle stopping system;
- Airborne defeat of MANPADS; and
- Airborne defeat of electronic systems.

## Features and Constraints of DE Weapons

### HEL Features[69]

Some basic HEL features include the following:

- Beams generated by HEL weapons reach targets at the speed of light; a destructive beam can travel great distances almost instantaneously, making it difficult for a target to evade the weapon system.
- For purposes of terrestrial-based weapons and targets, HEL beams are not affected by gravity or atmospheric drag. This lack of mass frees them from kinematic and aerodynamic constraints and also means that complex calculations required to determine ballistic trajectories and other flight characteristics of conventional munitions are not required.
- HEL weapons effects are extremely precise. This precision potentially makes it possible to undertake surgical strikes with little to no collateral damage or friendly fire casualties.

[68] Ibid., p. 25.

[69] Ibid., pp. 4-5.

- HEL weapons can be customized to achieve a range of results—lethal or nonlethal, destructive or disruptive. This is achieved by regulating the amount of energy and time focused on targets.
- HEL weapons cost relatively little to intercept targets compared with conventional munitions. For example, U.S. aircraft and missile defense missiles—the $3.3 million Patriot Advanced Capability-3 (PAC-3) missile; the $9 million Terminal High Altitude Area Defense (THAAD) missile; and the $10-15 million Standard Missile-3s (SM-3)—are employed against threat systems costing a fraction of these missiles' price tags.[70] By contrast, HEL weapons reportedly can cost as little as $30 a shot[71] while achieving an equivalent or superior probability of kill.[72]
- HEL weapons are less constrained by ammunition availability than conventional systems and have a much deeper "magazine"[73] than conventional weapons. HEL weapons can conduct repetitive engagements over a protracted period of time constrained only by the availability of power and requirements to vent beam generation by-products such as heat and chemicals.
- HEL weapons can also serve as sensors—not only attacking targets but detecting, imaging, tracking, and illuminating them as well.

## HEL Constraints[74]

Some basic HEL constraints include the following:

- HEL power dissipates with water vapor, dust, obscurants, and atmospheric turbulence, making them susceptible to terrain and adverse weather conditions.
- HEL beams travel in straight lines, meaning they are incapable of indirect fire over terrain and obstacles and cannot shoot beyond their visual horizon.[75]
- Depending on the HEL type, power requirements and beam generation by-products such as heat can significantly constrain the type of platform needed to accommodate the HEL weapon. For the Army, a challenge is mounting HELs on already size- and power-constrained ground combat and tactical wheeled vehicles. Developing a hand-held laser weapon to replace the current assault rifle, for example, could also prove particularly daunting when power generation and cooling requirements are factored into development.

[70] Gunzinger and Dougherty, pp. 14-15.

[71] U.S. Army Space and Missile Defense Command/Army Strategic Forces Command, "USASMDC/ARSTRAT High Energy Laser Efforts," November 2017, p. 3.

[72] "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, p. 5.

[73] Magazine refers to the number of munitions a weapon system can hold such as a 30 round magazine for a M-4 carbine or a destroyer's magazine of 3 inch shells for its guns.

[74] "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, p. 5.

[75] Alane Kochems and Andrew Gudgel, "The Viability of Directed-Energy Weapons," The Heritage Foundation, Washington, D.C., April 28, 2006.

### HPM Features[76]

Some basic HPM features include the following:

- HPM weapons can generate waves at different frequencies and power levels to temporarily or permanently disrupt certain types of electronic devices while leaving others unaffected.
- HPM weapons can also destroy a wide array of electronic targets both military and commercial.
- HPM weapons can also cause discomfort to humans and can serve as nonlethal weapons.
- HPM weapons can also potentially limit collateral damage to property and friendly fire casualties, making them attractive weapons in situations "short of war."

### HPM Constraints

Some basic HPM constraints include the following:

- HPM beams cannot be as tightly focused as lasers and energy per unit area for HPM beams decreases significantly over distance, potentially imposing significant operational limitations.[77]
- Because HPM weapons could affect all unshielded electronic systems within range, measures must be taken to insure that friendly systems are properly shielded to avoid collateral damage.[78]
- HPM beams can also be absorbed by any conductive material between the weapon and target, thereby lessening effectiveness.[79]

## Author Information

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[76] "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, p. 5.

[77] Gunzinger and Dougherty, p. 39.

[78] Ibid.

[79] "Directed-Energy Weapons: Technologies, Applications and Implications," The Lexington Institute, Washington D.C., June 6, 2003, Executive Summary.

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