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Navy Lasers, Railgun, and Hypervelocity Projectile: Background and Issues for Congress

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Summary

The Navy is currently developing three potential new weapons that could improve the ability of its surface ships to defend themselves against enemy missiles—solid state lasers (SSLs), the electromagnetic railgun (EMRG), and the hypervelocity projectile (HVP).

Any one of these new weapon technologies, if successfully developed and deployed, might be regarded as a "game changer" for defending Navy surface ships against enemy missiles. If two or three of them are successfully developed and deployed, the result might be considered not just a game changer, but a revolution. Rarely has the Navy had so many potential new types of surface-ship missile-defense weapons simultaneously available for development and potential deployment.

Although the Navy in recent years has made considerable progress in developing SSLs, EMRG, and HVP, a number of significant development challenges remain. Overcoming these challenges will likely require years of additional development work, and ultimate success in overcoming them is not guaranteed.

The issue for Congress is whether to approve, reject, or modify the Navy's funding requests and proposed acquisition strategies for these three potential new weapons. Potential oversight questions for Congress include the following:

- Using currently available approaches for countering anti-ship cruise missiles (ASCMs) and anti-ship ballistic missiles (ASBMs), how well could Navy surface ships defend themselves in a combat scenario against an adversary such as China that has large numbers of ASCMs (including advanced models) and ASBMs? How would this change if Navy surface ships in coming years were equipped with SSLs, EMRG, HVP, or some combination of these systems?
- How significant are the remaining development challenges for SSLs, EMRG, and HVP?
- Are current schedules for developing SSLs, EMRG, and HVP appropriate in relation to remaining development challenges and projected improvements in enemy ASCMs and ASBMs? To what degree are current schedules for developing SSLs, EMRG, or HVP sensitive to annual funding levels?
- When does the Navy anticipate issuing roadmaps detailing its plans for procuring and installing production versions of SSLs, EMRGs, and HVP on specific Navy ships by specific dates?
- Will the kinds of surface ships that the Navy plans to procure in coming years have sufficient space, weight, electrical power, and cooling capability to take full advantage of SSLs (particularly those with beam powers above 200 kW) and EMRG? What changes, if any, would need to be made in Navy plans for procuring large surface combatants (i.e., destroyers and cruisers) or other Navy ships to take full advantage of SSLs and EMRG?
- Are the funding sources for SSLs, EMRG, and HVP in Navy and Defense-Wide research and development accounts sufficiently visible for supporting congressional oversight?

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Introduction

Issue for Congress

This report provides background information and issues for Congress on three potential new weapons that could improve the ability of Navy surface ships to defend themselves against enemy missiles—solid state lasers (SSLs), the electromagnetic railgun (EMRG), and the hypervelocity projectile (HVP).[1]

Any one of these new weapon technologies, if successfully developed and deployed, might be regarded as a "game changer" for defending Navy surface ships against enemy missiles. If two or three of them are successfully developed and deployed, the result might be considered not just a game changer, but a revolution. Rarely has the Navy had so many potential new types of surface-ship missile-defense weapons simultaneously available for development and potential deployment. Although the Navy in recent years has made considerable progress in developing SSLs, EMRG, and HVP, a number of significant development challenges remain.

The issue for Congress is whether to approve, reject, or modify the Navy's funding requests and proposed acquisition strategies for these three potential new weapons. Congress' decisions on this issue could affect future Navy capabilities and funding requirements and the defense industrial base.

Scope of Report

SSLs are being developed by multiple parts of the Department of Defense (DOD), not just the Navy. SSLs, EMRG, and HVP, moreover, have potential application to military aircraft and ground forces equipment, not just surface ships. And SSLs, EMRG, and HVP can be used for missions other than defending against ASCMs and ASBMs.[2] This report focuses on Navy efforts to develop SSLs, EMRG, and HVP for potential use in defending Navy surface ships against ASCMs and ASBMs. It supersedes an earlier CRS report that provided an introduction to potential Navy shipboard lasers.[3]

Note that while fictional depictions of laser weapons in popular media often show them being used to attack targets at long ranges, the SSLs currently being developed by the Navy for potential shipboard use would be used to counter targets at short ranges of about a mile to perhaps a few miles.

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[1] Railgun is also spelled as rail gun; EMRG is also abbreviated as EM railgun; hypervelocity is also spelled as hyper-velocity or hyper velocity.

[2] As discussed later in the report, the Navy is exploring the potential for using shipboard lasers to counter small boats and unmanned aerial vehicles (UAVs), and EMRG can be used to attack land targets.

[3] CRS Report R41526, *Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress*, by Ronald O'Rourke. This earlier CRS report has been archived and remains available as a supplementary reference source on potential Navy shipboard lasers.

Background

Strategic and Budgetary Context

Concern about Survivability of Navy Surface Ships

Although Navy surface ships have a number of means for defending themselves against anti-ship cruise missiles (ASCMs) and anti-ship ballistic missiles (ASBMs),[4] some observers are concerned about the survivability of Navy surface ships in potential combat situations against adversaries, such as China, that are armed with advanced ASCMs and with ASBMs.[5] Concern about this issue has led some observers to conclude that the Navy's surface fleet in coming years might need to avoid operating in waters that are within range of these weapons, or that the Navy might need to move toward a different fleet architecture that relies less on larger surface ships and more on smaller surface ships and submarines.[6] Such changes in Navy operating areas and fleet architecture could substantially affect U.S. military strategy and the composition of the Navy's shipbuilding expenditures.

Navy surface fleet leaders in early 2015 announced a new organizing concept for the Navy's surface fleet called distributed lethality. Under distributed lethality, offensive weapons such as ASCMs are to be distributed more widely across all types of Navy surface ships, and new operational concepts for Navy surface ship formations are to be implemented. The aim of distributed lethality is to boost the surface fleet's capability for attacking enemy ships and make it less possible for an enemy to cripple the U.S. fleet by concentrating its attacks on a few very-high-value Navy surface ships (particularly the Navy's aircraft carriers).[7] Perspectives on whether

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[4] These include the following: operating ships in ways that make it hard for others to detect and accurately track Navy ships; jamming or destroying enemy targeting sensors; interfering with the transmission of targeting data from sensors to weapon launchers; attacking weapon launchers (which can land-based launchers or launchers on surface ships, submarines, or aircraft); and countering ASCMs and ASBMs headed toward Navy ships. Navy measures for countering ASCMs and ASBMs headed toward Navy ships include the following: jamming a missile's guidance system; using decoys of various kinds to lure enemy missiles away from Navy ships; and shooting down enemy missiles with surface-to-air missiles and the Phalanx Close-In Weapon System (CIWS), which is essentially a radar-controlled Gatling gun. Employing all these measures reflects a longstanding Navy approach of creating a multi-layered defense against enemy missiles, and of attacking the enemy's "kill chain" at multiple points so as to increase the chances of breaking the chain. (The kill chain is the sequence of steps that an enemy must complete to conduct a successful missile attack on a Navy ship. This sequence includes, at a basic level of description, detecting and tracking the Navy ship, passing that information from sensors to the weapon launcher, launching the weapon, and guiding the weapon all the way to the Navy ship. Interfering with any one of these actions can break the kill chain and thereby prevent or defeat the attack.)

[5] See, for example, Andrew F. Krepinevich, Maritime Warfare in a Mature Precision-Strike Regime, Washington, Center for Strategic and Budgetary Assessments, 2014, 128 pp. For more on China's ASCMs and ASBMs, see CRS Report RL33153, *China Naval Modernization: Implications for U.S. Navy Capabilities—Background and Issues for Congress*, by Ronald O'Rourke.

ASCMs and ASBMs are not the only reasons that some observers are concerned about the future survivability of U.S. Navy surface ships in combat situations; observers are also concerned about threats to U.S. Navy surface ships posed by small boats, mines, and torpedoes.

[6] See, for example, Phillip E. Pournelle, "The Deadly Future of Sea Control," *U.S. Naval Institute Proceedings*, July 2015: 26-31.

[7] See, for example, Thomas Rowden, Peter Gumataotao, and Peter Fanta, "Distributed Lethality," *U.S. Naval Institute Proceedings*, January 2015: 18-23; Sam LaGrone, "SNA: Navy Surface Leaders Pitch More Lethal Ships, Surface Action Groups," *USNI News*, January 14, 2015; Kris Osborn, "Navy Unveils New Surface Warfare Strategy," *Military.com*, January 14, 2015; Sydney J. Freedberg Jr., "'If It Floats, It Fights,': Navy Seeks 'Distributed Lethality,'" *Breaking Defense*, January 14, 2015; Mike McCarthy and Megan Eckstein, "Navy Eyeing A 'Hunter Killer' Surface (continued...)

it would be cost effective to spend money spreading offensive weapons across a wider array of Navy surface ships might be influenced by views on whether those surface ships can adequately defend themselves against enemy missiles.

Depth of Magazine and Cost Exchange Ratio

Two key limitations that Navy surface ships currently have in defending themselves against ASCMs and ASBMs are limited depth of magazine and unfavorable cost exchange ratios. Limited depth of magazine refers to the fact that Navy surface ships can use surface-to-air missiles (SAMs) and their Close-in Weapon System (CIWS) Gatling guns to shoot down only a certain number of enemy unmanned aerial vehicles (UAVs) and anti-ship missiles before running out of SAMs and CIWS ammunition[8]—a situation (sometimes called "going Winchester"), that can require a ship to withdraw from battle, spend time travelling to a safe reloading location (which can be hundreds of miles away),[9] and then spend more time traveling back to the battle area.

Unfavorable cost exchange ratios refer to the fact that a SAM used to shoot down a UAV or anti-ship missile can cost the Navy more (perhaps much more) to procure than it cost the adversary to build or acquire the UAV or anti-ship missile. In the FY2016 defense budget, procurement costs for Navy SAMs range from about $900,000 per missile to several million dollars per missile, depending on the type.[10]

In combat scenarios against an adversary with a limited number of UAVs and anti-ship missiles, an unfavorable cost exchange ratio can be acceptable because it saves the lives of Navy sailors and prevents very expensive damage to Navy ships. But in combat scenarios (or an ongoing military capabilities competition) against a country such as China that has many UAVs and anti-ship missiles and a capacity for building or acquiring many more, an unfavorable cost exchange ratio can become a very expensive—and potentially unaffordable—approach to defending Navy surface ships against UAVs and anti-ship missiles, particularly in a context of constraints on U.S. defense spending and competing demands for finite U.S. defense funds.

(...continued)

Fleet, Would Require Upgunning Existing Ship Fleets," *Defense Daily*, January 15, 2015: 1-3; Richard Scott, "Offensive Language: USN Sets Out Surface Firepower Strategy," *Jane's International Defence Review*, May 2015: 42-47; Megan Eckstein, "Navy Studying Implications of Distributed Lethality in Wargames Series," *USNI News*, July 9, 2015; Lara Seligman, "Navy Establishes Task Force To Study Impact of Distributed lethality," *Inside the Navy*, July 10, 2015.

[8] Navy cruisers have 122 missile cells; Navy destroyers have 90 or 96 missile cells. Some of these cells are used for storing and launching Tomahawk land attack cruise missiles or anti-submarine rockets. The remainder are available for storing and launching SAMs. A Navy cruiser or destroyer might thus be armed with a few dozen or several dozen SAMs for countering ASCMs and ASBMs. Countering ASCMs or ASBMs with SAMs might sometimes require shooting two SAMs at each ASCM or ASBM.

[9] The missile cells on a Navy cruiser or destroyers are clustered together in an installation called a Vertical Launch System (VLS). VLS cells cannot be reloaded while the ship is underway; a ship needs to return to a port or a calm anchorage to reload its VLS.

[10] Unit procurement costs for ship-launched SAMs in the FY2016 are as follows: about $900,000 for the Rolling Airframe Missile (RAM), about $1.1 million to about $1.5 million for the Evolved Sea Sparrow Missile (ESSM), about $3.9 million for the SM-6 Block 1 missile, about $14 million for the SM-3 Block 1B missile, and more than $20 million for theSM-3 Block IIA missiles. RAM and ESSM are short-range missiles for defense against aircraft and ASCMs. The SM-6 Block 1 is a medium-range missile used for both defense against aircraft and ASCMs, and terminal (i.e., endo-atmospheric) defense against theater-range ballistic missiles. The SM-3 Block 1B and SM-3 Block IIA are used for mid-course (i.e., exo-atmospheric) defense against theater-range ballistic missiles.

SSLs, EMRG, and HVP offer a potential for dramatically improving depth of magazine and the cost exchange ratio:

- **Depth of magazine.** SSLs are electrically powered, drawing their power from the ship's overall electrical supply, and can be fired over and over, indefinitely, as long as the SSL continues to work and the ship has fuel to generate electricity. The EMRG's projectile and the HVP (which are one and the same—see next section) can be stored by the hundreds in a Navy surface ship's weapon magazine.[11]
- **Cost exchange ratio.** An SSL can be fired for a marginal cost of less than one dollar per shot (which is the cost of the fuel needed to generate the electricity used in the shot), while the EMRG's projectile/HVP has an estimated unit procurement cost of about $25,000.[12]

For additional discussion of the strategic and budgetary context in which the programs discussed in this report and other Navy programs may be considered, see CRS Report RL32665, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, by Ronald O'Rourke.

SSLs, EMRG, and HVP in Brief

SSLs

The Navy in recent years has leveraged both significant advancements in industrial SSLs and decades of research and development work on military lasers done by other parts of DOD to make substantial progress toward deploying high-energy SSLs[13] on Navy surface ships. Navy surface ships would use high-energy SSLs initially for countering small boats UAVs, and potentially in the future for countering ASCMs and ASBMs as well.[14] High-energy SSLs on Navy ships would be short-range defensive weapons—they would counter targets at ranges of about one mile to perhaps eventually a few miles.[15]

In addition to a low marginal cost per shot and deep magazine, potential advantages of shipboard lasers include fast engagement times, an ability to counter radically maneuvering missiles, an ability to conduct precision engagements, and an ability to use lasers for graduated responses ranging from detecting and monitoring targets to causing disabling damage. Potential limitations

[11] In July 2015, the Navy issued a request for information (RFI) to industry for the fabrication of a prototype EMRG mount that would store a minimum of 650 rounds. (RFI for Fabrication of Prototype Mount for Naval Railgun, Solicitation Number: N00024-15-R-4132, FedBizOpps.gov, July 29, 2015. See also Justin Doubleday, "Navy Developing Integrated Mount For Electromagnetic Railgun," *Inside the Navy*, July 31, 2015.)

[12] Sources for cost of HVP: David Martin, "Navy's Newest Weapon Kills at Seven Times the Speed of Sound," CBS News (cbssnews.com), April 7, 2014; Kris Osborn, "Navy Will Test its Electromagnetic Rail Gun aboard DDG 1000," *DefenseTech*, April 15, 2015.

[13] In discussions of potential Navy shipboard lasers, a high-energy laser is generally considered to be a laser with a beam power of at least 10 kilowatts (kW).

[14] In general, lasers would counter small boats and missiles by heating and burning holes in their skins, and causing thermal damage to their interiors. Lasers can also be used to "dazzle" (i.e., interfere with) electro-optical sensors on a boat or missile.

[15] The Navy has also performed research and development work on a different kind of laser, called the free electron laser (FEL). In recent years, Navy research and development work on potential shipboard lasers has shifted more to SSLs. For background information on the FEL, see CRS Report R41526, *Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress*, by Ronald O'Rourke.

of shipboard lasers relate to line of sight; atmospheric absorption, scattering, and turbulence (which prevent shipboard lasers from being all-weather weapons); an effect known as thermal blooming that can reduce laser effectiveness; countering saturation attacks; possible adversary use of hardened targets and countermeasures; and risk of collateral damage, including damage to aircraft and satellites and permanent damage to human eyesight, including blinding. These potential advantages and limitations are discussed in greater detail in the **Appendix**.

Key developments in the Navy's high-energy SSL development effort include the following:

- Between 2009 and 2012, the Navy successfully tested a prototype SSL called the Laser Weapon System (LaWS) against UAVs in a series of engagements that took place initially on land and subsequently on a Navy ship at sea.
- Between 2010 and 2011, the Navy tested another prototype SSL called the Maritime Laser Demonstration (MLD) in a series of tests that culminated with an MLD installed on a Navy ship successfully engaging a small boat.
- In April 2013, the Navy announced that it planned to install LaWS on the USS Ponce (pronounced pon-SAY)—a converted amphibious ship that is operating in the Persian Gulf as an interim Afloat Forward Staging Base (AFSB[I]) [16]—to conduct evaluation of shipboard lasers in an operational setting against swarming boats and swarming UAVs.[17] The system was installed in August 2014 (see **Figure 1**, **Figure 2**, and **Figure 3**).
- In March 2014, it was reported that the Navy anticipated moving to a shipboard laser program of record in "the FY2018 time frame" and achieving an initial operational capability (IOC) with a shipboard laser in FY2020 or FY2021.[18]
- In December 2014, the Navy declared LaWS on the Ponce to be an "operational" system.[19]

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[16] An AFSB operates as a "mother ship" for Navy helicopter and small boat operations. The Ponce is serving as an interim AFSB pending the arrival of a new AFSB that is currently being built.

[17] "Navy Leaders Announce Plans for Deploying Cost-Saving Laser Technology," *Navy News Service*, April 8, 2013; Thom Shanker, "Navy Deploying Laser Weapon Prototype Near Iran," *New York Times*, April 9, 2013: 4; Mike McCarthy, "Navy Deploying Laser For Taking Out Drones," *Defense Daily*, April 9, 2013; Graham Warwick, "U.S. Navy Planning Gulf Deployment For Laser Weapon," *Aerospace Daily & Defense Report*, April 9, 2013: 6; Megan Eckstein, "Navy-Built Laser Weapon System Will Begin Demo On Ponce In Early 2014," *Inside the Navy*, April 15, 2013. See also Lara Seligman, "Navy-built LaWS To Begin Demo This Summer, IOC Slated For FY-20-21," *Inside the Navy*, March 24, 2014; Office of Naval Research, "All Systems Go: Navy's Laser Weapon Ready for Summer Deployment," *Navy News Service*, April 7, 2014.

Swarming refers to the use of boats and UAVs in large numbers, or swarms, in an attempt to confuse and overwhelm a target ship's defensive systems.

[18] Lara Seligman, "Navy-built LaWS To Begin Demo This Summer, IOC Slated For FY-20-21," *Inside the Navy*, March 24, 2014. A program of record, or POR, is a term sometimes used by DOD officials that means, in general, a program in the Future Years Defense Plan (FYDP) that is intended to provide a new, improved, or continuing materiel, weapon, or information system or service capability in response to an approved need. The term is sometimes used to refer to a program in a service's budget for procuring and deploying an operational weapon system, as opposed to a research and development effort that might or might not eventually lead to procurement and deployment of an operational weapon system.

[19] A December, 11, 2014, press report stated

> The Navy's first-of-a-kind laser deployed on a vessel sailing in the Persian Gulf has been declared operational and can be used by the crew to defend itself against potential threats, the service's head of the Office of Naval Research said on Wednesday [December 10, 2014].
>
> Rear Adm. Matthew Klunder told reporters on a conference call that Central Command has been green lighted to use the laser in the event of a threat, approval that has been passed along to the

(continued...)

Figure 1. Laser Weapon System (LaWS) on USS Ponce

Source: Navy photograph dated November 16, 2014, accompanying David Smalley, "Historic Leap: Navy Shipboard Laser Operates in Arabian Gulf," *Navy News Service*, December 10, 2014, accessed August 12, 2015, at http://www.navy.mil/list_all.asp?id=84805.

LaWS has a reported beam power of 30 kilowatts (kW),[20] which is strong enough to counter small boats and UAVs. As a follow-on effort to LaWS and MLD, the Navy initiated the SSL Technology Maturation (SSL-TM) program, in which industry teams led by BAE Systems, Northrop Grumman, and Raytheon are competing to develop a shipboard laser with a beam power of 100 kW to 150 kW, which would provide increased effectiveness against small boats and UAVs.[21] Boosting beam power further—to something like 200 kW or 300 kW—could permit a laser to counter at least some ASCMs. Even stronger beam powers—on the order of at least

(...continued)

> ship's commanding officer. The 30-kilowat laser, known as the Laser Weapon System, or LaWS, was installed on the USS Ponce in August [2014].
>
> The ship later departed for the Persian Gulf and the LaWS successfully carried out operational testing recently by striking a fast attack boat and drone, Klunder said, adding that this marks the "historic" first ever operational deployment of a directed energy weapon.
>
> (Mike McCarthy, "Navy Authorized To Use Ship-Based Laser In Battle," *Defense Daily*, December 11, 2014: 3. See also Sam LaGrone, "U.S. Navy Allowed to Use Persian Gulf Laser for Defense," *USNI News*, December 10, 2014; Philip Ewing, "Navy Declares Laser Weapon 'Operational,'" *Politico Pro (Pro Defense Report)*, December 10, 2014.)

[20] See, for example, Mike McCarthy, "Navy Authorized To Use Ship-Based Laser In Battle," *Defense Daily*, December 11, 2014: 3.

[21] For more on the SSL-TM program, see Office of Naval Research, "Solid-State Laser Technology Maturation Program," accessed August 11, 2015, at http://www.onr.navy.mil/Media-Center/Fact-Sheets/Solid-State-Laser-Technology-Maturation-Program.aspx; Office of Naval Research, "Solid State Laser Technology Maturation Program," September 2012, accessed August 11, 2015, at http://www.onr.navy.mil/~/media/Files/Fact-Sheets/35/Solid-State-Laser-Technology-Maturation-Program-2012-a.ashx; Office of Naval Research, "Research and Development/Technology Maturation of Solid State High Power Laser Weapon Systems, Subsystems, and/or Components for Surface Navy, USN, Broad Agency Announcement (BAA)," ONR BAA # 12-019, 2012, accessed August 11, 2015, at http://www.onr.navy.mil/~/media/files/funding-announcements/baa/2012/12-019.ashx; Future Force, "Developing a High-Energy Laser for the Navy," January 23, 2015, accessed August 11, 2015, at http://futureforce.navylive.dodlive.mil/2015/01/high-energy-laser/.

several hundred kW, if not one megawatt (MW) or more—could improve a laser's effectiveness against ASCMs and enable it to counter ASBMs.[22]

Figure 2. Laser Weapon System (LaWS) on USS Ponce

Source: Navy photograph dated November 17, 2014, accompanying David Smalley, "Historic Leap: Navy Shipboard Laser Operates in Arabian Gulf," *Navy News Service*, December 10, 2014, accessed August 12, 2015, at http://www.navy.mil/list_all.asp?id=84805.

A July 28, 2015, press report stated:

> [Secretary of the Navy Ray] Mabus said he would release a DE [directed energy][23] roadmap this fall that "charts our course for research, development, and fielding of high power radio frequency weapons, lasers, and directed energy countermeasures. And I will follow it up with my guidance to the Program Objective Memorandum for [Fiscal Year 2018],[24] which, importantly, establishes a resource sponsor and a program of record."...
>
> Also meant to help quicken the pace of progress, the Office of Naval Research will take lessons learned from the [USS] Ponce to inform the Solid State Laser Technology Maturation program that aims to produce a 100-150 kilowatt laser prototype for at-sea testing in 2018, or sooner if possible. Rear Adm. Bryant Fuller, Naval Sea Systems Command (NAVSEA) chief engineer, said... that everything the Navy learned about rules of engagement and how to use LaWS in an operational environment would apply to larger laser weapons as well. Leveraging the operational knowledge Ponce gained will help the Navy field whatever comes out of the SSL-TM effort much more rapidly.
>
> In the meantime, Mabus said the Laser Weapon System (LaWS) will continue its work in the Middle East after early success led officials to extend its deployment.[25]

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[22] For additional discussion, see CRS Report R41526, *Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress*, by Ronald O'Rourke, particularly the section entitled "Required Laser Power Levels for Countering Targets" and Appendix A on "Laser Power Levels Required to Counter Targets."

[23] Lasers and another class of weapons called high-power microwave (HPM) weapons are referred to collectively as directed-energy weapons because they achieve their effects by directing electromagnetic energy at their targets.

[24] The Program Objective Memorandum (POM) is an internal DOD document that guides the preparation of a budget for a particular fiscal year.

[25] Megan Eckstein, "Mabus: Adversaries Showing Interest in Directed Energy; Navy Needs to Move Faster," *USNI News*, July 28, 2015.

Figure 3. Laser Weapon System (LaWS) on USS Ponce

Source: Navy photograph dated November 16, 2014, accompanying David Smalley, "Historic Leap: Navy Shipboard Laser Operates in Arabian Gulf," *Navy News Service*, December 10, 2014, accessed August 12, 2015, at http://www.navy.mil/list_all.asp?id=84805.

EMRG

In addition to SSLs, the Navy since 2005 has been developing EMRG, a cannon that uses electricity rather than chemical propellants (i.e., gunpowder charges) to fire a projectile.[26] In EMRG, "magnetic fields created by high electrical currents accelerate a sliding metal conductor,

[26] Because it uses electricity rather than a powder charge to accelerate the projectile, Navy officials sometimes refer to EMRG as a launcher rather than a gun or cannon.

or armature, between two rails to launch projectiles at [speeds of] 4,500 mph to 5,600 mph,"[27] or roughly Mach 5.9 to Mach 7.4 at sea level.[28] Like SSLs, EMRG draws its power from the ship's overall electrical supply.[29] The Navy originally began developing EMRG as a naval surface fire support (NSFS) weapon for supporting U.S. Marines operating ashore, but subsequently determined that the weapon also has potential for defending against ASCMs and ASBMs.[30] In response to Section 243 of the FY2012 National Defense Authorization Act (H.R. 1540/P.L. 112-81 of December 31, 2011), the Navy in September 2012 submitted to the congressional defense committees a report on the EMRG development effort.[31]

Following tests with early Navy-built EMRG prototypes, the Navy funded the development of two industry-built EMRG prototype demonstrators, one by BAE Systems and the other by General Atomics (see **Figure 4** and **Figure 5**).

The two industry-built prototypes are designed to fire projectiles at energy levels of 20 to 32 megajoules,[32] which is enough to propel a projectile 50 to 100 nautical miles.[33] (Such ranges might refer to using the EMRG for NSFS missions. Intercepts of ASCMs and ASBMs might take place at much shorter ranges.) The Navy began evaluating the two industry-built prototypes in 2012.

[27] Grace Jean, "With a Bang, Navy Begins Tests on EM Railgun Prototype Launcher," Navy News Service, February 28, 2012, accessed August 12, 2015, at http://www.navy.mil/submit/display.asp?story_id=65577.

[28] The speed of sound in air (i.e., Mach 1), varies with altitude; at sea level, it is approximately 761 miles an hour. (See for example, the table entitled "Speed of Sound at Different Altitudes," accessed August 12, 2015, at http://www.fighter-planes.com/jetmach1.htm.

[29] Unlike SSLs, however, EMRG is not a directed energy weapon, because it achieves its effects by firing a physical projectile at the target, not by directing electromagnetic energy at the target. See also footnote 23.

[30] For a recent article discussing the use of EMRG in countering ASCMs and ASBMs, see Sam LaGrone, "Navy Wants Rail Guns to Fight Ballistic and Supersonic Missiles Says RFI," *USNI News*, January 5, 2015.

[31] U.S. Navy, *Electromagnetic Railgun System: Final Report to the Congressional Defense Committees*, August 2012, with cover letters dated September 18, 2012.

[32] The Navy states that "A megajoule is a measurement of energy associated with a mass traveling at a certain velocity. In simple terms, a one-ton vehicle moving at 100 mph equals a magajoule of energy." (Office of Naval Research Public Affairs, "Navy Sets New World Record with Electromagnetic Railgun Demonstration," *Navy News Service*, December 10, 2010, accessed August 12, 2015, at http://www.navy.mil/submit/display.asp?story_id=57690.)

[33] Grace Jean, "With a Bang, Navy Begins Tests on EM Railgun Prototype Launcher," Navy News Service, February 28, 2012, accessed August 12, 2015, at http://www.navy.mil/submit/display.asp?story_id=65577.

Figure 4. Industry-Built EMRG Prototype Demonstrator

BAE prototype

Source: Navy photograph dated July 8, 2014, associated with Office of Naval Research Public Affairs, "From Research to Railgun: Revolutionary Weapon at Future Force EXPO," *Navy News Service*, January 13, 2015, accessed August 12, 2015, at http://www.navy.mil/submit/display.asp?story_id=85166.

Figure 5. Industry-Built EMRG Prototype Demonstrator

General Atomics prototype

Source: navy photograph dated July 8, 2014, accessed August 12, 2015, at http://www.navy.mil/view_image.asp?id=180994.

In April 2014, the Navy announced that it plans to temporarily install a prototype EMRG aboard a Navy Joint High Speed Vessel (JHSV) in FY2016, for use in at-sea tests.[34] **Figure 6** is an artist's rendering of that installation.

[34] Naval Sea Systems Command Office of Corporate Communication, "Navy to Deploy Electromagnetic Railgun Aboard JHSV," *Navy News Service*, April 7, 2014, accessed August 12, 2015, at http://www.navy.mil/submit/display.asp?story_id=80055.

Figure 6. EMRG Prototype Demonstrator Installed on a JHSV

Artist's rendering

Source: Navy rendering dated March 13, 2014, associated with John Joyce, "CNO Tours Navy Electromagnetic Railgun and Directed Energy Facilities, Hosts All Hands Call," Navy News Service, September 5, 2014, accessed August 12, 2015, at http://www.navy.mil/submit/display.asp?story_id=83119.

Notes: In the temporary installation shown in the rendering, the weapon is placed on a tall platform to avoid having to cut through the ship's flight deck. In a permanent installation on a ship, only the top portion of the "pyramid" would be above deck, and the remainder of the equipment would be below the main deck, inside the ship's hull.

In January 2015, it was reported that the Navy is projecting that EMRG could become operational on a Navy ship between 2020 and 2025.[35] In April 2015, it was reported that the Navy is considering installing an EMRG on a Zumwalt (DDG-1000) class destroyer by the mid-2020s.[36]

HVP

As the Navy was developing EMRG, it realized that the guided projectile being developed for EMRG could also be fired from 5-inch and 155mm powder guns.[37] Navy cruisers each have two

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[35] Sam LaGrone, "Navy Wants Rail Guns to Fight Ballistic and Supersonic Missiles Says RFI," *USNI News*, January 5, 2015.

[36] Sam LaGrone, "Navy Considering Railgun for Third Zumwalt Destroyer," *USNI News*, February 5, 2015 (updated February 11, 2015); Mike McCarthy, "Navy Aiming To Put Railgun On Third Zumwalt Destroyer," *Defense Daily*, February 6, 2015; Kris Osborn, "Navy Will Test its Electromagnetic Rail Gun aboard DDG 1000," *DefenseTech*, April 15, 2015. For more on Zumwalt-class destroyers, see CRS Report RL32109, *Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress*, by Ronald O'Rourke.

[37] The Navy describes the HVP as "a next generation, common, low drag, guided projectile capable of completing multiple missions for gun systems such as the Navy 5-Inch, 155-mm, and future railguns.... HVP's low drag aerodynamic design enables high velocity, maneuverability, and decreased time-to-target. These attributes coupled with accurate guidance electronics provide low cost mission effectiveness against current threats and the ability to adapt to air and surface threats of the future." (Office of Naval Research, Hypervelocity Projectile," September 2012, accessed August 14, 2015, at http://www.onr.navy.mil/~/media/Files/Fact-Sheets/35/Hypervelocity-Projectile-2012B.ashx.) The Navy states that HVP weighs 23 pounds. (Source: David Martin, "Navy's Newest Weapon Kills at Seven Times the Speed of Sound," *CBS News (cbssnews.com)*, April 7, 2014.)

(continued...)

5-inch guns, and most Navy destroyers each have one 5-inch gun. The Navy's three new Zumwalt class (DDG-1000) destroyers, which are under construction, each have two 155mm guns.

The projectile is a hypervelocity projectile when fired from either EMRG or a powder gun, but the term HVP tends to be used more frequently in connection with the concept of firing it from a powder gun. **Figure 7** and **Figure 8** show the HVP.

Figure 7. Photograph Showing HVP

Source: Navy photograph dated April 4, 2014, with a caption that reads: "Rear Adm. Matthew Klunder, chief of naval research, shows off a Hypervelocity Projectile (HVP) to CBS News reporter David Martin during an interview held at the Naval Research Laboratory's materials testing facility. The HVP is a next-generation, common, low drag, guided projectile capable of completing multiple missions for gun systems such as the Navy 5-inch, 155-mm, and future railguns," accessed August 12, 2015, at http://www.navy.mil/view_image.asp?id=174517.

(...continued)

BAE Systems states that HVP is 24 inches long and weighs 28 pounds, including a 15-pound payload. The total length and weight of an HVP launch package, BAE Systems states, is 26 inches and 40 pounds. BAE states that the maximum rate of fire for HVP is 20 rounds per minute from a Mk 45 5-inch gun, 10 rounds per minute from the 155mm gun on DDG-1000 class destroyers (called the Advanced Gun System, or AGS), and 6 rounds per minute from EMRG. HVP's firing range, BAE Systems states, is more than 40 nautical miles (when fired from a Mk 45 Mod 2 5-inch gun), more than 50 nautical miles (Mk 45 Mod 4 5-inch gun), more than 70 nautical miles (155mm gun on DDG-1000 class destroyers), and more than 100 nautical miles (EMRG). (BAE Systems, "Hypervelocity Projectile (HVP)," 2014, accessed August 14, 2015, at http://www.baesystems.com/download/BAES_178505/hyper-velocity-projectile-hvp-datasheet.)

In July 2015, the Navy issued a request for information (RFI) to industry for the fabrication of a prototype EMRG mount capable of handling an integrated launch weight package of 22 kg, or about 48.5 pounds. (RFI for Fabrication of Prototype Mount for Naval Railgun, Solicitation Number: N00024-15-R-4132, FedBizOpps.gov, July 29, 2015. See also Justin Doubleday, "Navy Developing Integrated Mount For Electromagnetic Railgun," *Inside the Navy*, July 31, 2015.)

Figure 8. HVP

Source: Slide 7 from Navy briefing entitled "Electromagnetic Railgun," NDIA Joint Armaments Forum, Exhibition & Technology Demonstration, May 14, 2014, LCDR Jason Fox, USN, Assistant PM [Program Manager], Railgun Ship Integration, Distribution A, Approved for Public Release, accessed August 13, 2015, at http://www.dtic.mil/ndia/2014armaments/WedFox.pdf.

When fired from 5-inch powder guns, the projectile achieves a speed of roughly Mach 3, which is roughly half the speed it achieves when fired from EMRG, but more than twice the speed of a conventional 5-inch shell fired from a 5-inch gun.[38] This is apparently fast enough for countering at least some ASCMs. The Navy states that "The HVP—combined with the MK 45 [5-inch gun][39]—will support various mission areas including naval surface fire support, and has the capacity to expand to a variety of anti-air threats, [and] anti-surface [missions], and could expand the Navy's engagement options against current and emerging threats."[40]

One advantage of the HVP/5-inch gun concept is that the 5-inch guns are already installed on Navy cruisers and destroyers, creating a potential for rapidly proliferating HVP through the cruiser-destroyer force, once development of HVP is complete and the weapon has been

[38] Source: Sam LaGrone, "Updated: Navy Researching Firing Mach 3 Guided Round from Standard Deck Guns," *USNI News*, June 1, 2015 (updated June 2, 2015).

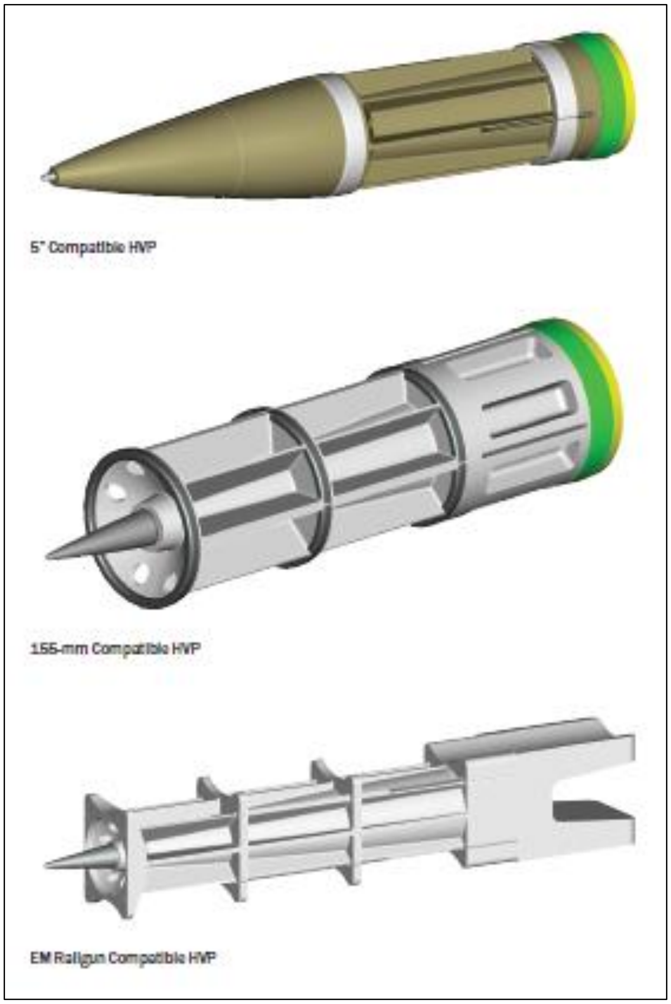
[39] The type of 5-inch gun on Navy cruisers and destroyers is called the Mark 45.

[40] Naval Surface Warfare Center Dahlgren Division Corporate Communications, "DEPSECDEF Loads HVP on Test Range, Observes Repetitive Rate Electromagnetic Railgun's Commissioning Series," *Navy News Service*, May 8, 2015, accessed August 12, 2015, at http://www.navy.mil/submit/display.asp?story_id=86987.

integrated into cruiser and destroyer combat systems. **Figure 9** shows HVP launch packages configured for 5-inch guns, 155mm guns, and EMRG.

Figure 9. HVP Launch Packages

Launch packages for 5-inch gun, 155mm gun, and EMRG

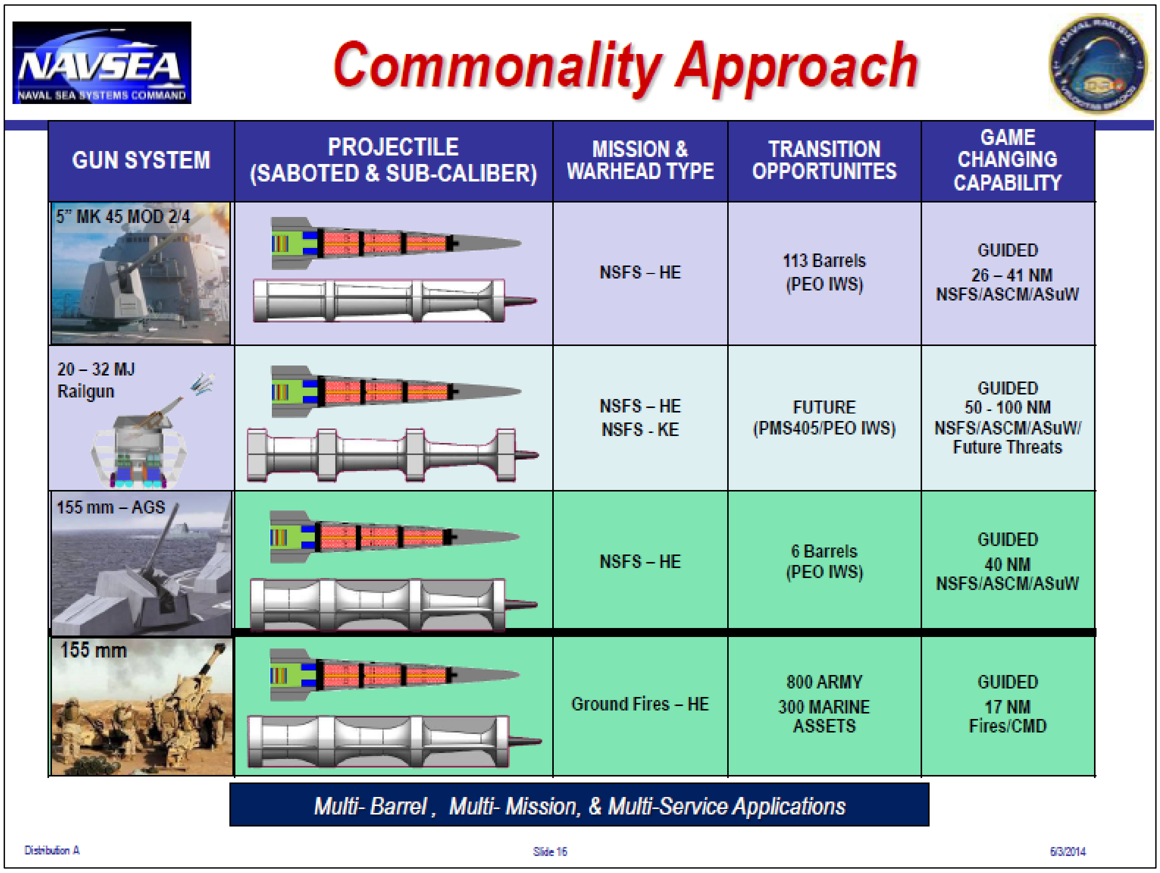


Source: BAE Systems, "Hypervelocity Projectile (HVP)," 2014, accessed August 14, 2015, at http://www.baesystems.com/download/BAES_178505/hyper-velocity-projectile--datasheet.

Figure 10 is a slide showing the potential application of HVP to 5-inch power guns, 155mm powder guns, and EMRG. The first line of the slide, for example, discusses HVP's use with 5-inch powder guns, stating that it uses a high-explosive (HE) warhead for the NSFS mission;[41] that a total of 113 5-inch gun barrels are available in the fleet (which could be a reference to 22 cruisers with two guns each, and 69 destroyers with one gun each); and that as a game-changing capability, it is guided and can be used at ranges of up to 26 nautical miles to 41 nautical miles for NSFS operations, for countering ASCMs, and for anti-surface warfare (ASuW) operations (i.e., attacking surface ships and craft).

[41] The "KE" in the next line down means that when fired from EMRG, the projectile can alternatively attack targets using its own kinetic energy (i.e., by simply impacting the target at hypersonic speed).

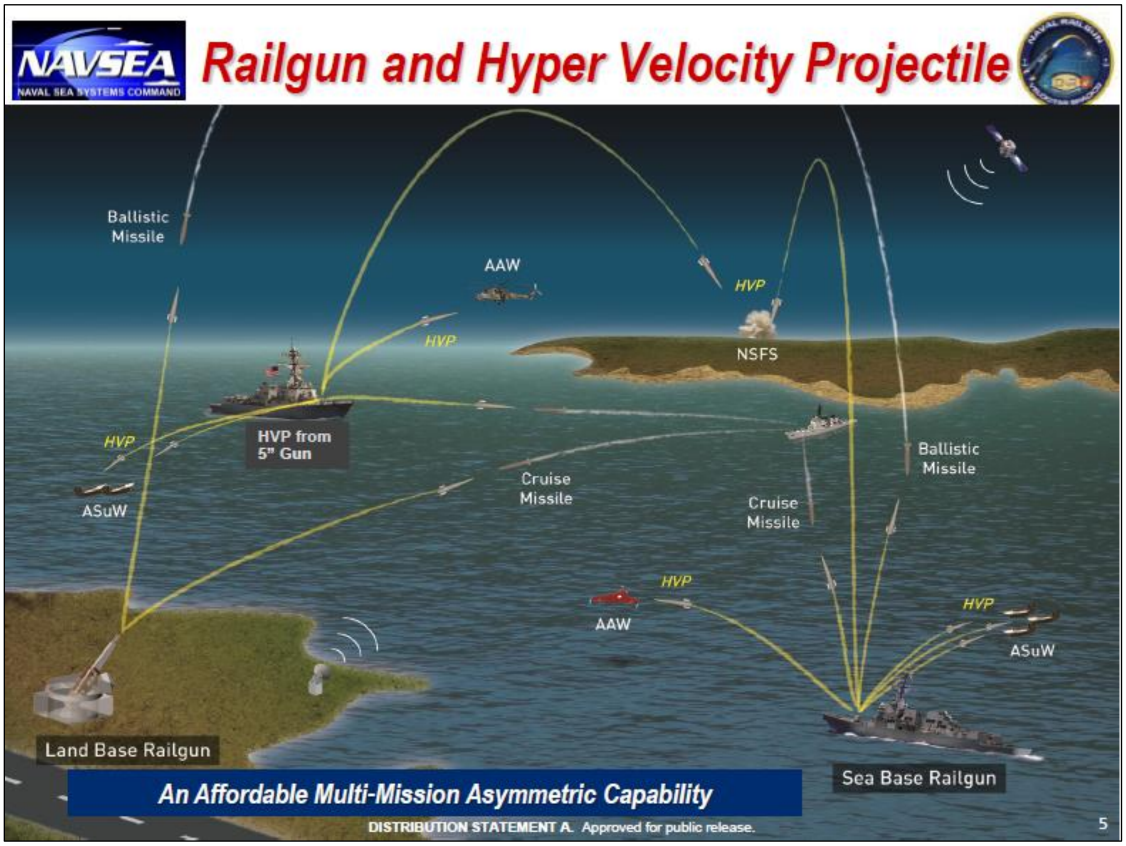
Figure 10. HVP Application to Various Launchers



Source: Slide 16 from Navy briefing entitled "Electromagnetic Railgun," NDIA Joint Armaments Forum, Exhibition & Technology Demonstration, May 14, 2014, LCDR Jason Fox, USN, Assistant PM [Program Manager], Railgun Ship Integration, Distribution A, Approved for Public Release, accessed August 13, 2015, at http://www.dtic.mil/ndia/2014armaments/WedFox.pdf.

Figure 11 is a not-to-scale illustration of how HVPs fired from EMRGs and 5-inch guns can be used to counter various targets, including ASCMs and ASBMs.

Figure 11. Navy Slide Depicting Operations Against Various Target Types



Source: Slide 5 from Navy briefing entitled "Electromagnetic Railgun," NDIA Joint Armaments Forum, Exhibition & Technology Demonstration, May 14, 2014, LCDR Jason Fox, USN, Assistant PM [Program Manager], Railgun Ship Integration, Distribution A, Approved for Public Release, accessed August 13, 2015, at http://www.dtic.mil/ndia/2014armaments/WedFox.pdf.

Indirectly Improving Ability to Counter ASCMs and ASBMs

As discussed earlier, SSLs currently under development have enough beam power to counter small boats and UAVs, but not enough to ASCMs or ASBMs. Even so, such SSLs could indirectly improve a ship's ability to counter ASCMs and ASBMs by permitting the ship to use fewer of its SAMs for countering UAVs, and more of them for countering ASCMs and ASBMs. Similarly, even though HVPs fired from 5-inch powder guns would not be able to counter ASBMs, they could indirectly improve a ship's ability to counter ASBMs by permitting the ship to use fewer of its SAMs for countering ASCMs and more of its SAMs for countering ASBMs.

Remaining Development Challenges

Although the Navy in recent years has made considerable progress in developing SSLs, EMRG, and HVP, a number of significant development challenges remain. Overcoming these challenges will likely require years of additional development work, and ultimate success in overcoming them is not guaranteed.[42]

[42] Laser skeptics sometimes note that laser proponents over the years have made numerous predictions about when (continued...)

SSLs

As shown in **Figure 12**, remaining development challenges for SSLs include, among other things, making the system rugged enough for extended shipboard use, making the beam director (the telescope-like part of the laser that sends the beam toward the target) suitable for use in a marine environment (where moisture and salt in the air can be harsh on equipment), and integrating the system into the ship's electrical power system and combat system.

Figure 12. Development Challenges for SSLs

As of February 2013

Source: Slide from Navy briefing entitled "Navy Solid State Laser Program Overview," ASNE Day 2013, Mr. Peter "Rollie" Morrison, ONR 35 S&T Program Office, February 22, 2013, accessed August 13, 2015, at https://www.navalengineers.org/ProceedingsDocs/ASNEDay2013/Morrison_Pres.pdf.

(...continued)

lasers might enter service with DOD, and that these predictions repeatedly have not come to pass. Viewing this record of unfulfilled predictions, skeptics might argue that "lasers are X years in the future—and always will be." Laser proponents acknowledge the record of past unfulfilled predictions, but argue that the situation has now changed because of rapid advancements in SSL technology and a shift from earlier ambitious goals (such as developing megawatt-power lasers for countering targets at tens or hundreds of miles) to more realistic goals (such as developing kilowatt-power lasers for countering targets at no more than a few miles). Laser proponents might argue that laser skeptics are vulnerable to what might be called cold plate syndrome (i.e., a cat that sits on a hot plate will not sit on a hot plate again—but it will not sit on a cold plate, either).

A January 23, 2015, blog post co-authored by the Office of Naval Research's program officer for the Navy's SSL program states:

> In the near term, many challenges remain to develop and operate high-energy laser systems in the maritime environment that are unique to the Navy and Marine Corps. Among these challenges is dealing with the heat generated as power levels increase. A second issue is packing sufficient power on the platform, which will require advanced battery, generator, power conditioning, and hybrid energy technologies. Current laser technologies are approximately 30 percent electrically efficient. Corrosion and contamination of optical windows by shipboard salt spray, dirt, and grime also are technical challenges. In addition, atmospheric turbulence resulting from shifting weather conditions, moisture, and dust is problematic. Turbulence can cause the air over long distances to act like a lens, resulting in the laser beam's diffusing and distorting, which degrades its performance.
>
> Much progress has been made in demonstrating high-energy laser weapon systems in the maritime environment, but there is still much to be done. Additional advances will be required to scale power levels to the hundreds of kilowatts that will make high[-]energy lasers systems robust, reliable, and affordable. Higher power levels are important for the ability to engage more challenging threats and improve the rate and range at which targets can be engaged.
>
> The programs managed by ONR are addressing these remaining issues while positioning this important warfighting capability toward an acquisition program and eventual deployment with the fleet and force.[43]

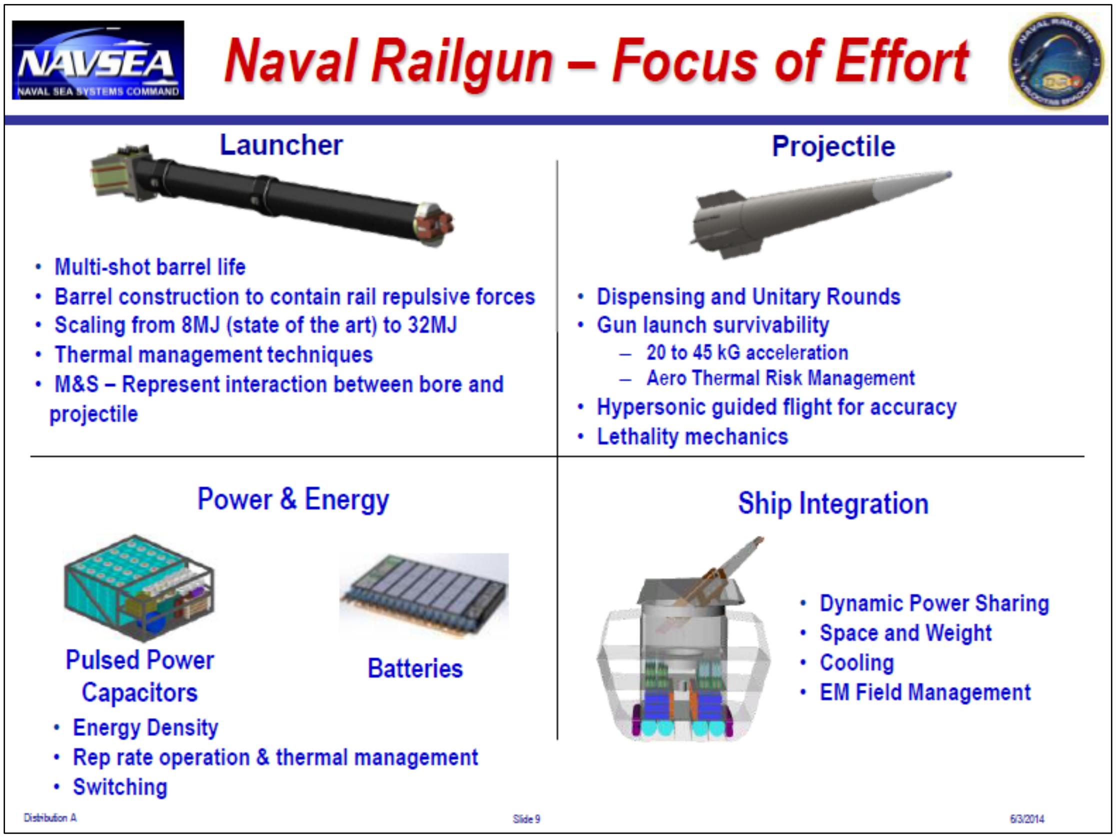
EMRG and HVP

As shown in **Figure 13**, remaining development challenges for EMRG involve items relating to the gun itself (including increasing barrel life to desired levels), the projectile, the weapon's electrical power system, and the weapon's integration with the ship. Fielding HVP on cruisers and destroyers ships equipped with 5-inch and 155mm powder guns would additionally require HVP to be integrated with the combat systems of those ships.

[43] Peter Morrison and Dennis Sorenson, "Developing a High-Energy Laser for the Navy," Future Force, January 23, 2015, accessed August 13, 2015, at http://futureforce.navylive.dodlive.mil/2015/01/high-energy-laser/. The authors are identified at the end of the post as follows: "Peter Morrison is the Office of Naval Research's program officer for the Navy's Solid-State Laser program. Dennis Sorenson is a contractor with the Office of Naval Research."

Figure 13. Development Challenges for EMRG

As of May 2014



Source: Slide 9 from Navy briefing entitled "Electromagnetic Railgun," NDIA Joint Armaments Forum, Exhibition & Technology Demonstration, May 14, 2014, LCDR Jason Fox, USN, Assistant PM [Program Manager], Railgun Ship Integration, Distribution A, Approved for Public Release, accessed August 13, 2015, at http://www.dtic.mil/ndia/2014armaments/WedFox.pdf.

The Navy states:

> The EMRG effort began in FY 2005 with a focus on the barrel, power storage, and rail technology. In 2015, the Navy is testing full-scale industry advanced composite launchers for structure strength and manufacturability, and has advanced the pulsed-power system design from single-shot to actively cooled repeated rate operations. Building on the success of the first phase, the second phase started in 2012 with a focus on developing equipment and techniques to fire ten rounds per minute. Thermal-management techniques required for sustained firing rates are in development for both the launcher system and the pulsed-power system. The Office of Naval Research will develop a tactical prototype EMRG launcher and pulsed-power architecture suitable for advanced testing both afloat and ashore. Railgun demonstration has been funded to occur in FY 2016.[44]

A June 2015 press report states:

> As the Navy prepares to test its electromagnetic railgun at sea for the first time in 2016, service leaders said one of the biggest challenges will be integrating the new technology onto existing platforms.....

[44] U.S. Navy, *U.S. Navy Program Guide 2015*, p. 169.

> [Vice Adm. William Hilarides, commander of Naval Sea Systems Command] said he is positive the Navy will successfully demonstrate the weapon's ability to fire from the Trenton, but one of the biggest challenges will be configuring the railgun so that it fits within the power structure of other existing platforms.
>
> "Those are not 600-ton margin ships," he said [meaning ships with 600 tons of growth margin available to accommodate EMRG]. "If they have 60 tons, if they have 16 tons, then we'll be talking about what do we take off our existing destroyers, cruisers and other ships in order to get this incredible capability [on them]."
>
> These types of discussions are influencing ship designs as program managers look at what systems are indispensable and what can be exchanged, Hilarides said.
>
> Integrating the railgun into the fleet won't be a swift process.
>
> It will be at least 10 years until the railgun is fielded on new ships and potentially 30 years past that before the Navy considers removing powder guns from the fleet entirely and transitioning to energy weapons alone, according to Hilarides.[45]

Issues for Congress

Potential Impact of Continuing Resolution (CR) for FY2016

One issue for Congress concerns the potential impact on Navy programs for SSLs, EMRG, and HVP of an extended continuing resolution (CR) or a full-year CR for FY2016. Extended or full-year CRs can lead to challenges in program execution because they typically prohibit the following:

- new program starts ("new starts"), meaning the initiation of new program efforts that did not exist in the prior year;
- an increase in procurement quantity for a program compared to that program's procurement quantity in the prior year; and
- the signing of new multiyear procurement (MYP) contracts.[46]

In addition, the Navy's shipbuilding account, known formally as the Shipbuilding and Conversion, Navy (SCN) appropriation account, is written in the annual DOD appropriation act not just with a total appropriated amount for the entire account (like other DOD acquisition accounts), but also with specific appropriated amounts at the line-item level. As a consequence, under a CR (which is typically based on the prior year's appropriations act), SCN funding is managed not at the account level (like it is under a CR for other DOD acquisition accounts), but at the line-item level. For the SCN account—uniquely among DOD acquisition accounts—this can lead to line-by-line misalignments (excesses and shortfalls) in funding for SCN-funded programs, compared to the amounts those programs received in the prior year. The shortfalls in particular can lead to program-execution challenges under an extended or full-year CR.

In addition to the above impacts, a CR might also require the agency (in this case, the Navy) to divide a contract action into multiple actions, which can increase the total cost of the effort by reducing economies of scale and increasing administrative costs.

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[45] Allyson Versprille, "Integration Biggest Challenge for Railgun," *National Defense*, June 2015. See also Lance M. Bacon, "3-Star: 'Lot of Work' Before Railgun Arrives in Fleet," Navy Times, February 5, 2015.

[46] For more on MYP contracts, see CRS Report R41909, *Multiyear Procurement (MYP) and Block Buy Contracting in Defense Acquisition: Background and Issues for Congress*, by Ronald O'Rourke and Moshe Schwartz.

The potential impacts described above can be avoided or mitigated if the CR includes special provisions (called anomalies) for exempting individual programs or groups of programs from the terms of the CR, or if the CR includes expanded authorities for DOD for reprogramming and transferring funds.

Potential Oversight Questions

Potential oversight questions for Congress regarding Navy programs for SSLs, EMRG, and HVP include the following:

- Using currently available approaches for countering ASCMs and ASBMs, how well could Navy surface ships defend themselves in a combat scenario against an adversary such as China that has large numbers of ASCMs (including advanced models) and ASBMs? How would this change if Navy surface ships in coming years were equipped with SSLs, EMRG, HVP, or some combination of these systems?
- How significant are the remaining development challenges for SSLs, EMRG, and HVP?
- Are current schedules for developing SSLs, EMRG, and HVP appropriate in relation to remaining development challenges and projected improvements in enemy ASCMs and ASBMs? To what degree are current schedules for developing SSLs, EMRG, or HVP sensitive to annual funding levels?
- When does the Navy anticipate issuing roadmaps detailing its plans for procuring and installing production versions of SSLs, EMRGs, and HVP on specific Navy ships by specific dates?
- Will the kinds of surface ships that the Navy plans to procure in coming years have sufficient space, weight, electrical power, and cooling capability to take full advantage of SSLs (particularly those with beam powers above 200 kW) and EMRG? What changes, if any, would need to be made in Navy plans for procuring large surface combatants (i.e., destroyers and cruisers) or other Navy ships to take full advantage of SSLs and EMRG?
- Are the funding sources for SSLs, EMRG, and HVP in Navy and Defense-Wide research and development accounts (see "Congressional Action on FY2016 Funding" below) sufficiently visible for supporting congressional oversight?

Legislative Activity for FY2016

Congressional Action on FY2016 Funding

Funding in the defense budget for research and development work on Navy SSLs, EMRG, and HVP is spread across several research and development account line items (which are known as program elements, or PEs). The PEs shown in the table below capture much but not necessarily all of the funding for developing Navy SSLs, EMRG, and HVP. The PEs shown in the table, moreover, include funding for efforts other than Navy SSLs, EMRG, and HVP, so congressional changes from requested amounts might or might not relate to SSLs, EMRG, or HVP.

Table 1. Summary of Congressional Action on FY16 Funding

In millions of dollars, rounded to nearest tenth

Program Element (PE) number, PE name, FY16 budget line number	Req.	Authorization			Appropriation		
		HASC	SASC	Conf.	HAC	SAC	Conf.
0602114N, Power Projection Applied Research, line 4	68.7	68.7	68.7		73.7	86.7	
0602750N, Future Naval Capabilities Applied Research, line 13	179.7	179.7	179.7		179.7	179.7	
0603114N, Power Projection Advanced Technology, line 15	37.1	37.1	37.1		37.1	37.1	
0603673N, Future Naval Capabilities Advanced Technology Development, line 20	258.9	248.9	248.9		265.9	258.9	
0603925N, Directed Energy and Electric Weapon System, line 73	67.4	67.4	67.4		55.2	40.2	
0604250D8Z, Advanced Innovative Technology, line 97	469,8	469.8	469.8		469.8	469.8	

Source: For request: Navy FY16 budget submission. For House Armed Services Committee (HASC): H.Rept. 114-102. For Senate Armed Services Committee (SASC): S.Rept. 114-49. For House Appropriations Committee (HAC): H.Rept. 114-139. For Senate Appropriations Committee (SAC): S.Rept. 114-63.

Notes: The PEs shown in the table below capture much but not necessarily all of the funding for work on Navy SSLs, EMRG, and HVP. The PEs shown in the table, moreover, include funding for efforts other than Navy SSLs, EMRG, and HVP.

FY2016 National Defense Authorization Act (H.R. 1735/S. 1376)

House

The House Armed Services Committee, in its report (H.Rept. 114-102 of May 5, 2015) on H.R. 1735, states:

> *Naval electric weapons systems fielding plan*
>
> The committee is aware that the Navy has been pursuing development and operational demonstration of a number of electric weapons systems, including both directed energy systems and electromagnetic railguns. This class of electric weapons has the potential to provide revolutionary new capabilities for Navy platforms, including increased range, increased safety, and deeper magazines than conventional weapons. The committee believes that such systems will be important in the future to counter cost-imposing strategies in an anti-access environment where swarms of low-cost weapons could be used to overwhelm higher-cost, limited numbers of defensive weapons. However, as the Navy continues to pursue increasing power and decreasing size for such weapons, the committee believes that the Navy should also be considering how to field and integrate such systems into future naval platforms in order to facilitate successful transition from the laboratory to the fleet.
>
> Therefore, the committee directs the Secretary of the Navy to develop a plan for fielding electric weapon systems within the Department of the Navy for both the current and future fleet, and to provide a briefing on the results of this plan to the House Committee on Armed Services by March 1, 2016. As part of this plan, the Secretary of the Navy shall detail proposals for the allocation of the requisite power and space for the fielding

> of electric weapons systems, such as the Laser Weapons System, electromagnetic railgun, or other similar systems currently in development for the current and future fleet. (Page 30)

Section 223 of H.R. 1735 as reported by the committee states (emphasis added):

> SEC. 223. Plan for advanced weapons technology war games.
>
> (a) Plan required.—The Secretary of Defense, in coordination with the Chairman of the Joint Chiefs of Staff, shall develop a plan for integrating advanced weapons technologies into exercises carried out individually and jointly by the military departments to improve the development and experimentation of various concepts for employment by the Armed Forces.
>
> (b) Elements.—The plan under subsection (a) shall include the following:
>
> (1) Identification of specific exercises to be carried out individually or jointly by the military departments under the plan.
>
> (2) Identification of emerging advanced weapons technologies based on joint and individual recommendations of the military departments, including with respect to **directed-energy weapons**, hypersonic strike systems,[47] autonomous systems, or other technologies as determined by the Secretary.
>
> (3) A schedule for integrating either prototype capabilities or table-top exercises into relevant exercises.
>
> (4) A method for capturing lessons learned and providing feedback both to the developers of the advanced weapons technology and the military departments.
>
> (c) Submission.—Not later than 180 days after the date of the enactment of this Act, the Secretary shall submit to the congressional defense committees the plan under subsection (a).

Regarding Section 223, H.Rept. 114-102 states (emphasis added):

> Section 223—Plan for Advanced Weapons Technology War Games
>
> This section would require the Secretary of Defense, in coordination with the Chairman of the Joint Chiefs of Staff, to develop a plan for integrating advanced technologies, such as **directed energy weapons**, hypersonic strike systems,[48] and autonomous systems, into broader title 10 war games to improve socialization with the warfighter and the development and experimentation of various concepts for employment by the Armed Forces. The Secretary would be required to submit the plan to the congressional defense committees not later than 180 days the date of the enactment of this Act.
>
> The committee believes that there are a number of emerging advanced weapons systems, like **directed energy, electromagnetic railguns**, hypersonics, and autonomous systems, that have the potential for dramatically enhancing the military effectiveness of U.S. forces. The committee has been concerned in the past with the transition of some of these science and technology concepts into fielded systems, and recognizes that there are a number of factors that can inhibit this transition. The committee believes that a significant factor is the lack of experimentation, concept development and war gaming that can be helpful in ironing out the technology, refining operating concepts and gaining warfighter trust and confidence in untested systems. The committee is aware of numerous

[47] The term "hypersonic strike systems" as used here may refer to certain potential long-range weapons that DOD is developing separately from HVP.

[48] See footnote 47.

historical examples in which experimentation with new technologies in peacetime have paved the way for their adoption and effective use in wartime. The committee believes that increasing integration of these new, advanced technology weapons systems into existing exercises, either as tangible prototypes or as conceptual excursions, could be valuable in promoting the experimentation needed to lay the foundation for successful technology adoption by the warfighting community. (Page 95)

H.Rept. 114-102 also states (emphasis added):

Defense Laboratory Enterprise Infrastructure

The committee recognizes the important role that the Defense Laboratory Enterprise plays, ensuring the United States maintains technological superiority, responding to the needs of the Department of Defense, and accelerating delivery of technical capabilities to the warfighter. To ensure the Defense Laboratory Enterprise is able to continue its mission, the committee believes it is important that the military departments make appropriate investments to sustain and recapitalize the infrastructure supporting the Defense Laboratory Enterprise. The committee notes that several critical technologies, including hypersonic weapons, **directed energy**, unmanned aerial systems and **electromagnetic railgun**, will potentially transition from development into production in the coming years. However, the budget request for fiscal year 2016 and the current Future Years Defense Program do not include military construction projects in support of the Defense Laboratory Enterprise.

Therefore, the committee directs the Secretary of Defense, in coordination with the Secretaries of the military departments, to provide a briefing to the House Committee on Armed Services by March 15, 2016, on the infrastructure supporting the Defense Laboratory Enterprise. At minimum, the briefing should address the current condition and capacity of existing infrastructure supporting defense laboratories, infrastructure-related investments made to defense laboratory infrastructure since fiscal year 2011, and the required infrastructure investments in laboratories, offices, and support facilities necessary in the coming years to synchronize Defense Laboratory capacity with the capability to transition emerging technologies into programs of record. (Pages 351-352)

Senate

Section 212 of S. 1376 as reported by the committee (S.Rept. 114-49 of May 19, 2015) states (emphasis added):

SEC. 212. Department of Defense technology offset program to build and maintain the military technological superiority of the United States.

(a) Program established.—

(1) IN GENERAL.—The Secretary of Defense shall establish a technology offset program to build and maintain the military technological superiority of the United States by—

(A) accelerating the fielding of offset technologies that would help counter technological advantages of potential adversaries of the United States, including **directed energy, low-cost, high-speed munitions**, autonomous systems, undersea warfare, cyber technology, and intelligence data analytics, developed using Department of Defense research funding and accelerating the commercialization of such technologies; and

(B) developing and implementing new policies and acquisition and business practices.

(2) GUIDELINES.—Not later than one year after the date of the enactment of this Act, the Secretary shall issue guidelines for the operation of the program, including—

(A) criteria for an application for funding by a military department, defense agency, or a combatant command;

(B) the purposes for which such a department, agency, or command may apply for funds and appropriate requirements for technology development or commercialization to be supported using program funds;

(C) the priorities, if any, to be provided to field or commercialize offset technologies developed by certain types of Department research funding; and

(D) criteria for evaluation of an application for funding or changes to policies or acquisition and business practices by a department, agency, or command for purposes of the program.

(b) Development of directed energy strategy.—

(1) IN GENERAL.—Not later than one year after the date of the enactment of this Act, the Secretary, in consultation with such officials and third-party experts as the Secretary considers appropriate, shall develop a directed energy strategy to ensure that the United States directed energy technologies are being developed and deployed at an accelerated pace.

(2) COMPONENTS OF STRATEGY.—The strategy required by paragraph (1) shall include the following:

(A) A technology roadmap for directed energy that can be used to manage and assess investments and policies of the Department in this high priority technology area.

(B) Proposals for legislative and administrative action to improve the ability of the Department to develop and deploy technologies and capabilities consistent with the directed energy strategy.

(C) An approach to program management that is designed to accelerate operational prototyping of directed energy technologies and develop cost-effective, real-world military applications for such technologies.

(3) BIENNIAL REVISIONS.—Not less frequently than once every 2 years, the Secretary shall revise the strategy required by paragraph (1).

(4) SUBMITTAL TO CONGRESS.—(A) Not later than 90 days after the date on which the Secretary completes the development of the strategy required by paragraph (1) and not later than 90 days after the date on which the Secretary completes a revision to such strategy under paragraph (3), the Secretary shall submit to the Committee on Armed Services of the Senate and the Committee on Armed Services of the House of Representatives a copy of such strategy.

(B) The strategy submitted under subparagraph (A) shall be submitted in unclassified form, but may include a classified annex.

(c) Applications for funding.—

(1) IN GENERAL.—Under the program, the Secretary shall, not less frequently than annually, solicit from the heads of the military departments, the defense agencies, and the combatant commands applications for funding to be used to enter into contracts, cooperative agreements, or other transaction agreements entered into pursuant to section 845 of the National Defense Authorization Act for Fiscal Year 1994 (Public Law 103–160; 10 U.S.C. 2371 note) with appropriate entities for the fielding or commercialization of technologies.

(2) TREATMENT PURSUANT TO CERTAIN CONGRESSIONAL RULES.—Nothing in this section shall be interpreted to require any official of the Department of Defense to

> provide funding under this section to any earmark as defined pursuant to House Rule XXI, clause 9, or any congressionally directed spending item as defined pursuant to Senate Rule XLIV, paragraph 5.
>
> (d) Funding.—
>
> (1) IN GENERAL.—Subject to the availability of appropriations for such purpose, of the amounts authorized to be appropriated for research, development, test, and evaluation, Defense-wide for fiscal year 2016, not more than $400,000,000 may be used for any such fiscal year for the program established under subsection (a).
>
> **(2) AMOUNT FOR DIRECTED ENERGY.—Of this amount, not more than $200,000,000 may be used for activities in the field of directed energy.**
>
> (e) Transfer authority.—
>
> (1) IN GENERAL.—The Secretary may transfer funds available for the program to the research, development, test, and evaluation accounts of a military department, defense agency, or a combatant command pursuant to an application, or any part of an application, that the Secretary determines would support the purposes of the program.
>
> (2) SUPPLEMENT NOT SUPPLANT.—The transfer authority provided in this subsection is in addition to any other transfer authority available to the Department of Defense.
>
> (f) Termination.—
>
> (1) IN GENERAL.—The authority to carry out a program under this section shall terminate on September 30, 2020.
>
> (2) TRANSFER AFTER TERMINATION.—Any amounts made available for the program that remain available for obligation on the date the program terminates may be transferred under subsection (e) during the 180-day period beginning on the date of the termination of the program.

Regarding Section 212, S.Rept. 114-49 states (see in particular the parts in bold):

> **Department of Defense technology offset program to build and maintain the military technological superiority of the United States (sec. 212)**
>
> The committee notes with concern that the United States has not faced a more diverse and complex array of crises since the end of World War II, and that taken together, they constitute the greatest challenge in a generation to the integrity of the liberal world order, which has consistently been underwritten by U.S. military technological superiority. At the same time, the committee is alarmed by the apparent erosion in recent years of this technological advantage, which is in danger of disappearing altogether. To prevent such a scenario and to maintain the country's global military technological edge, the committee recommends a provision that would establish a new $400.0 million initiative.
>
> In doing so, the committee notes that the Defense Department is facing an emerging innovation gap. Commercial research and development in the United States now represents 80 percent of the national total, and the top four U.S. defense contractors combined spend only one-quarter of what the single biggest internet company does on research and development. Furthermore, global research and development is now more than twice that of the United States. The committee also notes that defense innovation is moving too slowly—in cycles that can last up to 18 years, whereas commercial innovation can be measured in cycles of 18 months or less.
>
> The committee understands that accessing sources of innovation beyond the Defense Department is critical for national security, particularly in the areas of **directed energy, low-cost high-speed munitions**, cyber capabilities, autonomous systems, undersea warfare, and intelligence data analytics. However, there are currently too many barriers

that limit cooperation with U.S. allies and global commercial firms, posing a threat to the country's future military technological dominance.

For the past several years, U.S. adversaries have been rapidly improving their own military capabilities to counter our unique advantages. Structural trends, such as the diffusion of certain advanced military technologies, pose new operational challenges to U.S. armed forces. As a result, the dominance of the United States military can no longer be taken for granted. Consequently, the Department of Defense must remain focused on the myriad potential threats of the future and thus maintain technological superiority against potential adversaries.

The committee notes that since 1960, the department has invested more than $6.0 billion in directed energy science and technology initiatives. The committee is concerned that, despite this significant investment, the department's directed energy initiatives are not resourced at levels necessary to transition them to full-scale acquisition programs. The committee is encouraged by the Navy's demonstration a 100–150 kilowatt prototype laser and by the Air Force's demonstration of high-powered electromagnetic weapons capabilities. However, the committee is concerned about the future of directed energy technologies as a whole. The committee notes that there is no inter-service entity dedicated to advancing promising directed energy platforms beyond the development point towards acquisition.

The committee is encouraged that the department established a department-wide Defense Innovation Initiative in November 2014 to pursue innovative ways to sustain and advance our military superiority and to improve business operations throughout the department. However, the committee is concerned by the possibility that this initiative is not being implemented in an appropriate and expeditious manner.

In response to these factors, the committee recommends a provision that would establish an initiative within the Department of Defense to maintain and enhance the military technological superiority of the United States. The provision would establish a program to accelerate the fielding of offset technologies, including, but not limited to, **directed energy, low-cost high-speed munitions**, autonomous systems, undersea warfare, cyber technology, and intelligence data analytics, developed by the department and to accelerate the commercialization of such technologies. As part of this program, the committee expects that the Secretary of Defense would also establish updated policies and new acquisition and management practices that would speed the delivery of offset technologies into operational use.

The provision would authorize $400.0 million for fiscal year 2016 for the initiative, of which $200.0 million would be authorized specifically for directed energy technology. Accordingly, the provision would mandate the Secretary to develop a directed energy strategy to ensure that appropriate technologies are developed and deployed at an accelerated pace, and update it every 2 years. The committee expects that this strategy would include a recommendation on rationalizing the roles and authorities of the Joint Technology Office for High Energy Lasers. The provision would further direct the Secretary to submit this strategy to the Senate Armed Services Committee and the House Armed Services Committee no later than 90 days after completing the strategy, and biennially thereafter.

To speed up the development of these vitally needed national security capabilities, the committee directs that the Secretary of Defense shall consider all appropriate flexible acquisition authorities granted in law and in this Act. These should include the management structure and streamlined procedures for rapid prototyping outlined in section 803 of this Act on the middle tier of acquisition for rapid prototyping and rapid fielding, and the procedures and authorities to be considered under section 805 of this Act

> on use of alternative acquisition paths to acquire critical national security capabilities to include other transactions, rapid acquisition, and commercial item authorities.
>
> The committee expects that the Secretary of Defense would keep the Senate Committee on Armed Services and the House Committee on Armed Services regularly updated on progress of activities under this technology offsets initiative. (Pages 44-46)

S.Rept. 114-49 also states:

> **Cost estimate for a land-based electromagnetic railgun program**
>
> The committee is aware that the efforts within the Navy to develop an electromagnetic railgun have been successful in demonstrating early capabilities for naval applications. Further, the committee recognizes that the Navy's initial success has spawned investments within the Strategic Capabilities Office of the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics to pursue development of a land-based electromagnetic railgun to support missile defense.
>
> Recognizing that such investments are still in the demonstration phase, the committee believes it is important to do as much as possible to plan concurrently for how to proceed with railgun technology to improve the possibility of transition into a program of record. Therefore, the committee directs the Director of Cost Assessment and Program Evaluation (CAPE) to conduct a cost estimate for a land-based electromagnetic railgun program, and provide the results to the Senate Armed Services Committee and the House Armed Services Committee by January 1, 2016. As part of the cost estimate briefing, CAPE should examine the potential costs for the projected life cycle of the railgun system, as well as comparison of those costs against current systems and other systems supporting missile defense missions projected to be fielded in the next 10 years. (Page 68)

FY2016 DOD Appropriations Act (H.R. 2685/S. 1558)

House

The House Appropriations Committee, in its report (H.Rept. 114-139 of June 5, 2015) on H.R. 2685, recommends reducing by $12.124 million the Navy's FY2016 funding request for 0603925N, with the reduction being for "Railgun excess support" ($6 million) and "Program execution" ($6.124 million) (page 236, line 73).

Senate

The Senate Appropriations Committee, in its report (S.Rept. 114-63 of June 1, 2015) on S. 1558, recommends reducing by $27.1 million the Navy's FY2016 funding request for 0603925N, with the reduction being for "Restoring acquisition accountability: Long lead materials for non-competitive test event in fiscal year 2019" (page 163, line 73). S.Rept. 114-63 states:

> *Directed Energy*.—The fiscal year 2016 budget request includes $67,360,000 for a sea-based demonstration of an electromagnetic railgun on board a Joint High Speed Vessel in fiscal year 2016 and to purchase materials for a second, more complex sea-based demonstration in fiscal year 2019. The Committee continues its strong support for an electromagnetic railgun program, but remains concerned with the Navy's acquisition approach to this developmental program that has limited competition for major components more than 5 years before the program is scheduled to enter the formal Department of Defense acquisition process. The Committee notes that the proposed complex fiscal year 2019 sea-based demonstration continues to drive the Navy towards a single material solution. The Committee does not agree with this acquisition approach

and recommends no funds for the fiscal year 2019 sea-based demonstration. (Pages 165-166)

Appendix. Potential Advantages and Limitations of Shipboard Lasers

This appendix presents additional information on potential advantages and limitations of shipboard lasers.

Potential Advantages

In addition to a low marginal cost per shot and deep magazine, potential advantages of shipboard lasers include the following:

- **Fast engagement times.** Light from a laser beam can reach a target almost instantly (eliminating the need to calculate an intercept course, as there is with interceptor missiles) and, by remaining focused on a particular spot on the target, cause disabling damage to the target within seconds. After disabling one target, a laser can be redirected in several seconds to another target.
- **Ability to counter radically maneuvering missiles.** Lasers can follow and maintain their beam on radically maneuvering missiles that might stress the maneuvering capabilities of Navy SAMs.
- **Precision engagements.** Lasers are precision-engagement weapons—the light spot from a laser, which might be several inches in diameter, affects what it hits, while generally not affecting (at least not directly) separate nearby objects.
- **Graduated responses.** Lasers can perform functions other than destroying targets, including detecting and monitoring targets and producing nonlethal effects, including reversible jamming of electro-optic (EO) sensors. Lasers 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

Potential limitations of shipboard lasers include the following:

- **Line of sight.** Since laser light tends to fly through the atmosphere on an essentially straight path, shipboard lasers would be limited to line-of-sight engagements, and consequently could not counter over-the-horizon targets or targets that are obscured by intervening objects. This limits in particular potential engagement ranges against small boats, which can be obscured by higher waves, or low-flying targets. Even so, lasers can rapidly reacquire boats obscured by periodic swells.
- **Atmospheric absorption, scattering, and turbulence.** Substances in the atmosphere—particularly water vapor, but also things such as sand, dust, salt particles, smoke, and other air pollution—absorb and scatter light from a shipboard laser, and atmospheric turbulence can defocus a laser beam. These effects can reduce the effective range of a laser. 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 the ship, on a constant bearing (i.e., "down-the-throat" shots). Other ship self-defense systems, such as interceptor missiles or a CIWS, might be more suitable for countering such targets. 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 laser can attack only one target at a time, requires several seconds to disable it, and several more seconds to be redirected to the next target, a laser 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 ship simultaneously or within a few seconds of one another. This limitation can be mitigated by installing more than one laser on the ship, similar to how the Navy installs multiple CIWS systems on certain ships.
- **Hardened targets and countermeasures.** Less-powerful lasers—that is, lasers with beam powers measured in kilowatts (kW) rather than megawatts (MW)—can have less effectiveness against targets that incorporate shielding, ablative material, or highly reflective surfaces, or that rotate rapidly (so that the laser spot does not remain continuously on a single location on the target's surface) or tumble. Small boats could employ smoke or other obscurants to reduce their susceptibility to laser attack. Measures such as these, however, can increase the cost and/or weight of a weapon, and obscurants could make it more difficult for small boat operators to see what is around them, reducing their ability to use their boats effectively.
- **Risk of collateral damage to aircraft, satellites, and human eyesight.** Since light from an upward-pointing laser that does not hit the target would continue flying upward in a straight line, it could pose a risk of causing unwanted collateral damage to aircraft and satellites. The light emitted by SSLs being developed by the Navy is of a frequency that can cause permanent damage to human eyesight, including blinding. Blinding can occur at ranges much greater than ranges for damaging targeted objects. Scattering of laser light off the target or off fog or particulates in the air can pose a risk to exposed eyes.[49]

[49] The United States in 1995 ratified the 1980 Convention on Prohibitions or Restriction on the Use of Certain Conventional Weapons Which May be Deemed to be Excessively Injurious or to Have Indiscriminate Effects. An international review of the convention began in 1994 and concluded in May 1996 with the adoption of, among other things, a new Protocol IV on blinding laser weapons. The protocol prohibits the employment of lasers that are (continued...)

For additional background information on potential Navy shipboard SSLs, see CRS Report R41526, *Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress*, by Ronald O'Rourke.

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(...continued)

specifically designed to cause permanent blindness to the naked eye or to the eye with corrective eyesight devices. The United States ratified Protocol IV on December 23, 2008, and it entered into force for the United States on July 21, 2009. DOD views the protocol as fully consistent with DOD policy. DOD believes the lasers discussed in this report are consistent with DOD policy of prohibiting the use of lasers specifically designed to cause permanent blindness to the naked eye or to the eye with corrective eyesight devices. For further discussion, see Appendix I ("Protocol on Blinding Lasers") in CRS Report R41526, *Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress,* by Ronald O'Rourke.