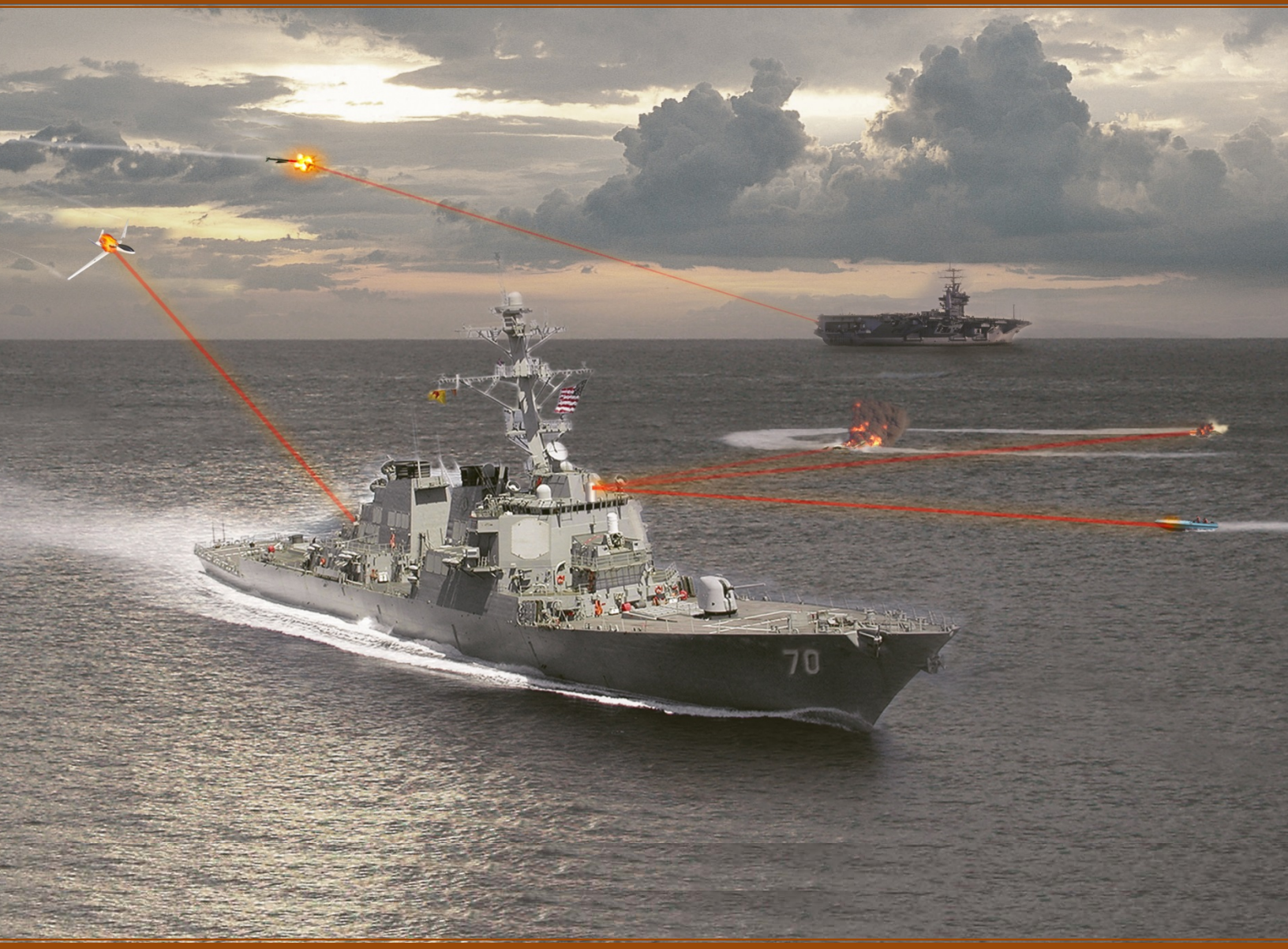
THE NEXT U.S. ASYMMETRIC ADVANTAGE

Maritime Lasers to Counter the A2/AD Challenge



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The Next U.S. Asymmetric Advantage: Maritime Lasers to Counter the A2/AD Challenge

Executive Summary

The United States Navy is confronted by an expanding array of both qualitative and quantitative threats to its ability to conduct its fundamental missions of forward presence, sea control, power projection ashore and defense of the global commons. The proliferation of advanced, long-range anti-ship missiles, particularly when coupled to a robust C4ISR system, is complicating operational planning and could, in the event of hostilities, deny the Navy the ability to operate in critical parts of the world's oceans. Even individually less capable threats such as fast attack craft and armed unmanned aerial vehicles could seriously drain inventories of defensive weapons.

Directed energy systems, including solid-state and fiber optic lasers and the electromagnetic projectile launcher, have the potential to help address these threats as well as perform additional high value missions. The inherent characteristics of laser weapons, speed of light engagement, precision targeting, rapid shot generation and tunability, offer the opportunity for expanded engagement options against a range of threats. These features can enhance the ability of naval units to defeat large raids and to counter short time-of-flight threats such as rockets, mortars and artillery shells. Equally important, laser weapons could bend the cost-exchange curve between offensive and defensive systems that appears at present to favor the former over the latter. When not employed as a weapon system, the inherent electro-optical/infrared properties of laser weapons could be used as a high fidelity intelligence, surveillance and reconnaissance sensor. Maritime laser weapons (MLW) have the potential to help counter the range of threats the Navy will have to confront.

The first generation of deployed naval directed energy weapons may be just around the corner. The Navy's Maritime Laser Demonstrator (MLD) was able to track and defeat small surface targets. This year, the Navy will deploy the MLD at sea, on the USS *Ponce*, tying the laser into shipboard combat and power systems. The Navy's near-term goal for the prototype system is 30 kilowatts (kW) with an objective power level of around 150 kW by 2016. At this power level, a laser weapons system would be capable of addressing the threat posed by unmanned aerial vehicles, small boats, rockets, artillery and mortars. It is a relatively short leap from the Navy's 150 kW technology demonstrator to a fully capable directed energy weapon. Based on progress to date, the Navy could have a fully capable laser weapon deployed within a decade.

The requirement for a transformational capability such as the MLW is clear. Progress on the technology has been significant; with the completion of the prototype MLW system the technology readiness level for the critical technologies will be a seven out of ten. Given the Navy's clear need for directed energy weapons, and should the ongoing technology development efforts mature, the Navy needs to be prepared to rapidly transition to a program of record. This means planning for the necessary funding in the fiscal 2016 budget, formulating the appropriate requirements documents for a naval laser weapon and developing the detailed architectural plans to deploy weapons aboard both current and future surface combatants.

The Opportunity to Change the Game

The realization is setting in that the military superiority enjoyed by the United States over the two decades following the collapse of the Soviet Union and the end of the Cold War is eroding. Adversaries of all types have "gone to school" on the so-called American Way of War in order to identify weaknesses that could be exploited. In some instances this meant selective investment in advanced capabilities. In other cases, prospective adversaries have sought to create leverage by deploying large numbers of relatively simple and low-cost platforms and systems in order to overwhelm their more technologically-sophisticated opponents or just create an unfavorable cost-exchange ratio.

China is deploying a wide variety of long-range weapons including one ship-killing, precision-guided ballistic missile. Iran has a mixed array of conventional aircraft, ships, and tanks along with sea-skimming cruise missiles, long-range ballistic missiles, advanced sea mines, and swarms of small boats. Many countries are deploying surface-to-air missiles and other capabilities intended to deny the U.S. its long-held advantage in airpower. Hezbollah, Iran's surrogate, now deploys a massive arsenal of rockets and missiles, anti-armor guided missiles and mines, and squad-level automatic weapons to complement its traditional asymmetric weapons such as snipers and suicide bombers. The same proliferation will likely occur in man-portable anti-aircraft weapons, thereby challenging U.S. dominance in close air support.

Recent analyses have pointed out that the U.S. is losing its monopoly in advanced military capabilities to state and non-state actors alike. This has already taken place in communications and even intelligence thanks to sources such as Google Earth. It is rapidly becoming the case with a wide range of advanced weapons and the training that goes with them. Both China and Russia have programs underway to develop their own fifth-generation fighters, advanced offensive and defensive missile systems, and even weapons in space. Allies, friends and adversaries alike are investing heavily in unmanned aerial systems, electronic warfare and cyber weapons.

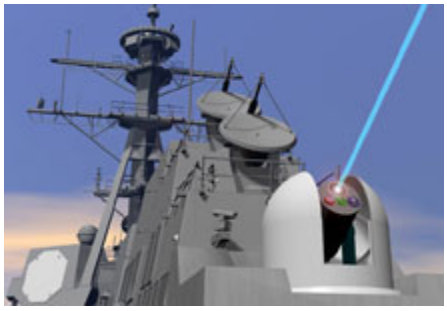
While prospective adversaries have been searching for advantages and acquiring a wide range of new systems and weapons, the U.S. lost a decade or more of time during which it should have been modernizing its conventional forces and, arguably, investing in so-called transformational capabilities. Many critical modernization programs such as the F-22 and F-35 fighters, new long-range strike system, air and sea-based missile defenses and the DDG-1000 destroyer were either truncated, delayed or reduced in scope or capability.

It is not enough simply to modernize existing capabilities with next-generation platforms, systems or weapons. Defense decision makers need to focus on what can be done to change strategic and operational trajectories that appear increasingly unfavorable to the United States. Consideration needs to be given to "game changing" investments that undermine those areas where prospective adversaries enjoy comparative advantages, thereby forcing a change in their strategies, negating their investments in costly capabilities, and even bending to our advantage the cost-exchange ratio between U.S. systems and theirs.

Directed energy weapons have been said to offer the potential to transform warfare for decades, with their combination of deep magazines, long range, precision engagement at the speed of light and relatively low cost per shot. Past efforts to develop a militarily-effective and affordable laser weapon system had limited success. Over the past several years, however, research and development (R&D) demonstrations have proceeded to a point that suggests a solid-state maritime laser weapon could have a significant impact on future naval operations.

The potential for directed energy weapons at sea is supported by advances in power generation capabilities that are or can be deployed on newer U.S. Navy ships. The technology exists today to deploy a 150 kilowatt (kW) laser on a DDG-51 Flight 2A destroyer and the Littoral Combat Ship. By using a duty cycle and battery storage system, a battle rhythm can be developed that allows existing power/cooling advances to provide the necessary laser capability to defend against swarms of fast attack and fast inshore attack craft and unmanned aerial vehicles (UAVs). While this would not allow 24/7 operations due to recharge time, no weapon system is used continuously. A battery option with a reasonable duty cycle would allow for sufficient time to rapidly engage multiple small boats.

Integrated power systems (IPS) offer the potential to support even more powerful directed energy systems. IPS already have been deployed on a number of ships including the DDG-1000 *Zumwalt*, the Mobile Landing Platform, LHA-8 and LPD-6 amphibious ships, and is planned for the Ohio-class nuclear submarine replacement.[1] An IPS could be deployed on future Flight III Arleigh Burke DDGs. The innovative high-voltage, high-power system on the new Ford-class aircraft carrier that will power the new electromagnetic aircraft launch system also will support directed energy weapons.



The SSL-TM program is a research and development project to mature solid-state, high-power laser weapon systems and components for ship defense.

> The improved nuclear-propulsion system, manned at only half of the *Nimitz* propulsion-plant crew size, and a zonal electric distribution scheme will increase electric power-generation capacity by more than 300 percent, powering revolutionary technologies such as directed-energy weapons, the electromagnetic aircraft-launch system (EMALS), and dual-band radar.[2]

The combination of the changing threat and advances in directed energy technologies suggests that it is time for a reconsideration of the role of this potential game-changing capability and, in particular, for the Navy to consider a serious commitment to a maritime laser program.

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[1] PEO Ships Electric Ships Office, "Innovative Integration: The IPS Advantage," http://www.navsea.navy.mil/teamships/PEOS_ElectricShips/ESO_Integration.aspx (n.d.). Lauren Maffeo, "General Dynamics NASSCO Commissions Converteam to Supply Power Systems to US Navy," *GovCon Executive* (August 3, 2011). Kris Osborn, "Ohio Replacement Subs to Shift to Electric Drive," *Military.com* (September 27, 2013).
[2] Rear Admiral Michael C. Manazir, "Responsive and Relevant," *Proceedings*, Volume 140, No. 2 (February, 2014).

The U.S. Military Faces Intensifying Challenges

The U.S. Navy is confronted by an expanding array of both qualitative and quantitative threats to its ability to conduct its fundamental missions of forward presence, sea control, power projection ashore and defense of the global commons. The proliferation of advanced, long-range anti-ship missiles, particularly when coupled to a robust C4ISR system is complicating operational planning and could, in the event of hostilities, deny the Navy the ability to operate in critical parts of the world's oceans.

> Given the proliferation of sophisticated weapons in the world's arms markets, potential enemies -- even relatively small powers -- will be able to possess and deploy an array of longer-range and more precise weapons. Such capabilities in the hands of America's enemies will obviously threaten the projection of forces into a theater, as well as attack the logistical flow on which U.S. forces will depend. Thus, the projection of military power could become hostage to the ability to counter long-range systems even as U.S. forces begin to move into a theater of operations and against an opponent. The battle for access may prove not only the most important, but the most difficult.[3]

Such investments are part of an overall strategy called Anti-Access/Area Denial (A2/AD) intended to impede the ability of all U.S. forces to project power rapidly and unimpeded anywhere in the world. The anti-access element of the strategy is intended to force an adversary to operate from outside their effective range by attacks on fixed forward bases, ports of debarkation, troop and logistics concentrations, naval formations, and command, control, and communication nodes employing massed strikes by ballistic and cruise missiles, manned aircraft and even unmanned systems. The area denial strategy is focused on interfering with the ability of opposing forces to operate locally once access has been achieved by employing a variety of means including integrated air defense systems, sea mines, small fast attack boats and diesel-electric submarines.

A number of major regional powers, most notably Iran and China, are pursuing what can be described as robust A2/AD strategies. They are acquiring capabilities and developing forces and operational concepts designed to limit the ability of hostile forces to rapidly project military power into theater and conduct early, high-intensity aerospace operations. Practitioners of an A2/AD strategy, whether nations such as China, Iran, Syria and North Korea or non-state actors such as Hezbollah and Hamas, seek to employ a combination of advanced technologies and sheer quantity to defeat their adversaries' defenses and countermeasures.

Beijing's investment in A2/AD is part of a broad and deep program of military modernization:

> The pace and scope of China's military build-up already puts regional military balances at risk. China is likely to continue making large investments in high-end, asymmetric military capabilities, emphasizing electronic and cyber-warfare; counter-space operations; ballistic and cruise missiles; advanced integrated air defense systems; next generation torpedoes; advanced submarines; strategic nuclear strike from modern,

[3] U.S. Joint Forces Command, *The Joint Operating Environment 2010* (February 18, 2010), p. 63.

> sophisticated land and sea-based systems; and theater unmanned aerial vehicles for employment by the Chinese military and for global export.[4]

A key aspect of the People's Republic of China's A2/AD strategy is to extend its defensive envelope eastward past what is termed the First Island Chain which runs from Japan through the Ryukyu Islands to Taiwan and then south to the Philippines. A recent article in a prominent Chinese military publication declared that "The PLAN *[People's Liberation Army Navy]* has cut up the whole island chain into multiple sections so that the so-called island chains are no longer existent." The People's Liberation Army's investments in a massive arsenal of theater ballistic missiles, land, air and sea-launched cruise missiles, fourth (and soon fifth) generation combat aircraft and modern surface combatants and submarines is clearly intended to deny access by the U.S. Navy to East Asia.

China also is working on advanced weapons technologies that could negate current U.S. capabilities and require development of entirely new offensive and defensive capabilities. On January 9, 2013, China tested a hypersonic vehicle atop an intercontinental ballistic missile. A hypersonic weapon travels at more than five times the speed of sound. Once launched into space, this vehicle separates from its booster and then maneuvers at the edge of the atmosphere at speeds up to a dozen times that of sound. Hypersonic weapons, like the first long-range ballistic missile, will totally transform conventional warfare making sitting ducks of aircraft and surface ships. The U.S. Navy is already having trouble defending against slower supersonic anti-ship missiles; it has no defense against a hypersonic weapon.

Iran is investing heavily in A2/AD capabilities in order to compensate for its weakness in conventional forces. Having witnessed close hand what U.S. air and naval forces were capable of in Iraq and Afghanistan, the regime in Teheran understands the risks it entails should U.S. forces be allowed unfettered access to the region and Iranian airspace.

> Iran's efforts include a mix of weapons and other military technologies to allow its conventional forces to try to exploit the weakness in US, allied, and Arab Gulf conventional forces. They include a wide range of steadily growing land, air, missile, and naval capabilities in its Islamic Revolutionary Guard Corps. These include small, hard to detect, elements for naval mine and missile warfare in the Gulf, training hostile and extremist elements in other countries, and steadily expanding long range missile forces controlled by the IRGC that can already strike at targets anywhere in the region and are the logical delivery systems if Iran produces nuclear weapons.[5]

Even a small number of advanced anti-ship weapons could significantly constrain the operation of U.S. naval forces. In 2006 Hezbollah struck an Israeli gunboat off the coast of Lebanon with a Chinese-made anti-ship cruise missile. Russia, in particular, is exporting advanced, high-speed anti-ship missiles such as the Shkval and Klub. According to *The Economist*, a Russian

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[4] U.S. Department of Defense, *Quadrennial Defense Review Report* (February 6, 2006), pp. 29-30. See also, U.S. Department of Defense, *Military and Security Developments involving the People's Republic of China* (2011), p. 27-30.

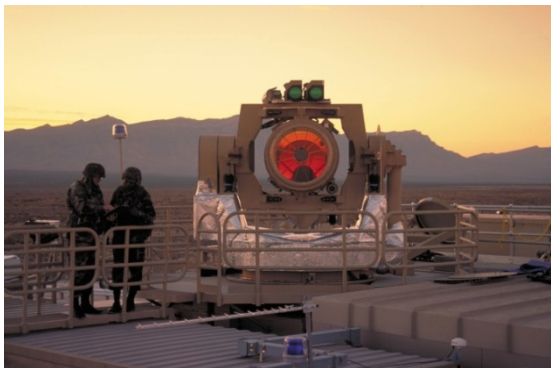
[5] Anthony Cordesman, Bryan Gold and Garrett Bernsten, *The Gulf Military Balance Volume I: The Conventional and Asymmetric Dimensions*, Center for Strategic and International Studies (Washington, DC, Jan 28, 2014), p. 120.

company is offering to construct a missile battery consisting of four Klub missiles, an erector/launcher and a two-man launch control center that will all fit into a standard shipping container.[6]

The quantity, variety and quality of threats to U.S. ships are increasing. The Navy will require a range of responses in order to deal with them. These responses will have to address not only the most advanced anti-ship weapons but also seek to bend if not break the cost-exchange curve involving massed strikes with less complex and expensive systems.

Evolving Capabilities to Support Maritime Lasers

The history of directed energy weapons has been marked by high expectations not entirely matched by progress on the critical technologies. There have also been difficulties in the basic generation and management of energy beams, defining the appropriate concept of operations (CONOPS) for the employment of such systems, and dealing with the logistics and safety issues associated with hazardous chemicals.



The THEL program was recently terminated, but not until after proving that it was possible to hit and destroy fast moving, and even short time-of-flight targets.

The defense R&D system has been promising for more than 30 years to deliver directed energy weapons. The original Strategic Defense Initiative envisioned a variety of directed energy weapons from a ground-based free electron laser to a space-based, nuclear bomb pumped x-ray laser. That was one of the reasons the program got stuck with the label Star Wars.

While those systems were never realized, the R&D community did manage to develop some useful capabilities. The U.S. Army and Israel began cooperative development of a Tactical High Energy Laser (THEL) in the late 1990s. By the early 2000s the testbed version of the THEL shot down 33 Katyusha artillery rockets and artillery shells, including several multiple engagements. At the same time, the U.S. Air Force was working on an airborne laser (ABL). In 2010 this system demonstrated that it could shoot down a ballistic missile in flight. Unfortunately, for a number of reasons -- the immaturity of many of the component technologies for both the THEL and airborne laser, the fact that they were both chemical lasers and needed large amounts of very dangerous chemicals in order to operate, the high cost of developing an operational system and, particularly in the case of the ABL, its CONOPS -- both programs were eventually terminated. But they had both proven that it was possible to hit and destroy fast moving, and even short time-of-flight targets.

The first generation of directed energy weapons may be just around the corner. Earlier this year, the Army conducted a test of its solid-state High Energy Laser Mobile Demonstrator (HEL MD)

[6] "A Shot in the Dark," *The Economist* (November 30, 2013), pp. 58-59.

at White Sands. The demonstrator is a low-powered (10-15 kW) laser mounted on a single large vehicle yet it was able to knock out multiple rockets, mortars and artillery shells in mid-flight. It also demonstrated the ability to counter the electro-optical sensors mounted on unmanned aerial vehicles.[7]

Lockheed Martin is working on the Area Defense Anti-Munitions (ADAM) system, a fiber optic laser. At 10 kW, the ADAM has successfully engaged an unmanned aerial system target in flight at a range of approximately 1.5 kilometers (km) and has destroyed four small-caliber rocket targets in simulated flight at a range of approximately 2 km. The fiber optics laser consumes approximately 50 percent less power than a more conventional solid-state laser for the same output.[8]

The focus of these current efforts, including the Navy's solid-state Maritime Laser Demonstrator (MLD), offer a number of advantages compared to earlier chemical laser programs. As evidenced by the MLD, the technology has reached a relatively high level of maturity and can be successfully employed without the operational, support and safety issues associated with chemical lasers.

The Office of Naval Research (ONR) has been at the forefront of the effort to bring laser weapons to the fleet. ONR's Solid State Laser Technology Maturation (SSL-TM) program is a research and development project to mature solid-state, high-power laser weapon systems and components for ship defense. Under this program, the Navy's Maritime Laser Demonstrator (MLD) at Sea, conducted in April 2011, successfully demonstrated all aspects of a maritime laser weapon system: target acquisition, beam pointing, power generation and control, thermal control and integration with ship combat systems. The MLD was able to track and defeat small surface targets.[9] Also, it has shown a capability for passive tracking and identification of relatively small targets such as UAVs and small boats.

The Navy also is working to develop an electromagnetic projectile launcher, or railgun. The program has successfully demonstrated the ability to accelerate a small projectile to the hypersonic speed of Mach 7. The current program is focused on demonstrating the capacity for sustained firing rates.[10]

The Army and Navy programs show not only how far the technologies required to field a directed energy weapon have come but also how much the military has learned about managing such high tech and potentially transformative programs. Both the Army and Navy systems use solid-state lasers, doing away with all the problems and costs associated with the earlier chemical laser systems. Advances in component technologies such as the modules that form the heart of these lasers but also those for power generation and management, beam control, jitter compensation and target tracking allow for a lower cost, greater reliability and enhanced effectiveness of the systems. Unlike their predecessors, both current programs have cost just

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[7] Graham Warwick, "Beam Power," *Aviation Week and Space Technology* (December 23, 2013).
[8] Prachi Patel, "Lockheed Martin Shows Off High-Power Fiber Laser Weapon," *IEEE Spectrum* (February 7, 2014).
[9] "Navy Will Get Lasers in 2 Years, Admiral Says," *TechNewsDaily* (October 24, 2012).
[10] Office of Naval Research, "Electromagnetic Railgun," http://www.onr.navy.mil/media-center/fact-sheets/electromagnetic-railgun.aspx (n.d.).

tens of millions of dollars, in part because they have both leveraged the work done by others, including the U.S. Air Force. Finally, rather than attempting to build the ultimate directed energy weapon from the start, both programs have adhered to the crawl, walk, run approach.

The next step is to move from the MLD to a prototype weapons system. The prototype will need to be more compact and lighter weight, produce more power, interface with shipboard systems and be capable of extended operations at sea. The current ONR program seeks to mature the relevant technologies, building one or two systems for testing at sea. The near-term or threshold capability for the prototype system is 30 kW with an objective power level of around 150 kW by 2016. At 150 kW, a laser weapons system would be capable of addressing the threat posed by UAVs, small boats, rockets, artillery and mortars. It would take power levels between several hundred kilowatts and a megawatt to have an effective capability to counter manned aircraft and ballistic or cruise missiles.

Senior Navy leaders see the laser program as one of the service's highest priorities and a potential game changer in the effort to expand the capabilities of surface ships and defeat the emerging A2/AD threat.

> Our directed energy initiatives, and specifically the solid-state laser, are among our highest priority science and technology programs. The solid-state laser program is central to our commitment to quickly deliver advanced capabilities to forward-deployed forces. This capability provides a tremendously affordable answer to the costly problem of defending against asymmetric threats, and that kind of innovative approach is crucial in a fiscally constrained environment.[11]

With this vision of the future of maritime lasers in mind, the Chief of Naval Operations, Admiral Jonathan Greenert, is seeking to accelerate the current program. He has directed that laser weapon systems (LaWS), following successful land-based testing in 2012, be deployed aboard the USS *Ponce* (LPD-15) for demonstration in summer 2014.

In addition, the Navy has conducted exercises and simulations to determine the CONOPS that would be associated with maritime laser weapons. Such efforts are designed to explore operation of both the laser system and supporting sensors across the entire kill chain. A simulation exercise tested these capabilities with the synthetic aperture radar, UAVs, signals intelligence and other intelligence data. Also, it addressed weather impact and duty cycle thresholds in order to develop a draft playbook for laser weapons system operations. The information and CONOPS developed through the simulation will support the demonstration to be conducted in 2014.

The Navy is on the cusp of being able to deploy a tactically effective laser system within a few years. A 150 kW solid-state laser weapons system could be tested in the next two years. Running a 100 kW laser is the equivalent to running a 750 horse-power engine. This level of power is readily available on current classes of warships without major internal reconfiguration. An equally significant technology advance is the introduction of Integrated Power Systems on

[11] Chief of Naval Research Rear Admiral Matthew Klunder cited in Gail Overton, "U.S. Navy to deploy laser weapon aboard ship in Persian Gulf," *Laser Focus World* (April 2013).

several classes of surface ships. By allowing access to the full power generation capability of these vessels, IPS can enable a range of novel capabilities from advanced sensors and electronic warfare to different directed energy and electronic weapon systems.

The remaining challenges to a maritime laser weapon are shipboard integration, power generation, distribution and management on ship classes without IPS and cooling of the weapon itself. Because of the intermittent demands of a directed energy weapon on the power system, power management and storage would need to be carefully handled. These are not insurmountable challenges.

The Navy recognized the need to address the increasing demand for power across virtually all classes of ship. The number of sensors, computers and electronic systems aboard Navy ships is growing exponentially. Next-generation radar systems have large power requirements to operate continuously as well as to generate pulse power. Advanced weapons systems also have increased the demand for power. The Next-Generation IPS Roadmap is designed to respond to projections of increasing need for advanced power systems able not only to generate more power but to manage changing load requirements.[12]

A Vision of the Future Navy

In 2007, the Defense Science Board (DSB) identified directed energy weapons as being of particular importance to the U.S. Navy in order to counter the growing anti-ship cruise missile threat.

> … the Navy has a need for an effective high-energy laser system for defending high-value ships against supersonic missiles. Existing stressing threats are represented by a new anti-ship missile with a rocket-propelled warhead that has the ability for high-g defensive maneuvers as it approaches its target. Particular characteristics make the warhead a particularly difficult system to counter with kinetic energy weapons.[13]

More broadly, directed energy weapons have the potential to answer the threat to U.S. and coalition forces posed by the proliferation of longer-range precision strike systems. There is a growing consensus among defense experts that directed energy systems could be a decisive response to the threat posed by large numbers of such weapons. According to a study by the Center for Strategic and Budgetary Assessments:

> The unique attributes of future DE *[directed energy]* capabilities—including their ability to produce precise and tailored effects against multiple targets, their "speed-of-light" responsiveness, and their deep magazines—could allow them to support a wide range of missions and create new opportunities for the U.S. military to gain a disruptive advantage in the emerging precision-guided weapons regime. Simply stated, future DE capabilities

[12] Electric Ships Office, PMS 320, *Naval Power Systems Technology Development Roadmap*, Naval Sea Systems Command (May 14, 2013).
[13] Defense Science Board, *Task Force Report on Directed Energy Weapons*, Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics (December 2007), p. 23.

> could lead to a new military technology "breakout." Moreover, their much lower cost per shot compared to expendable kinetic munitions could help reestablish a cost-imposition dynamic that is favorable to U.S. forces. From a resource perspective, a future DE-enabled U.S. military could reduce its overall requirements to procure, deploy, store, and maintain large inventories of conventional weapons such as ballistic missile interceptors, thus freeing DoD *[Department of Defense]* funds for other priority investments.[14]

The Center for a New American Security suggested that directed energy weapons could change the cost-exchange ratio between the offense and defense in favor of the latter:

> As guided munitions and battle networks proliferate, legacy power projection platforms and bases will be vulnerable to saturation attack from large numbers of long-range guided weapons, such as ballistic and cruise missiles, unless defenders can find interception methods with favorable cost-exchange ratios. As previously discussed, the guided munitions-battle network regime is offensive dominant, which imposes both great burdens and costs on a defender. Shooting two $10 million to $15 million interceptors against a single inbound ballistic missile to ensure a successful engagement is a losing proposition over the long run in a guided munitions salvo competition. This will be even truer when defending against future arming attacks by unmanned systems. Electric weapons, such as electromagnetic rail guns and high-energy lasers, with high rates of fire and low cost per shot, could help redress both near-term and far-term problems. As such, military planners are aggressively pursuing them. High-powered microwave weapons that disrupt electronics likewise have tremendous potential. Such weapons could disable enemy weapons and electronic systems through nonlethal means and could potentially be employed with a greater degree of autonomy in unmanned systems. With the development of smaller, high density power generation systems, these systems could be made much more compact, making them available on future battlefields in increasing numbers.[15]

Maritime laser weapons (MLW) have the potential to help counter the range of threats the Navy will have to confront. The inherent characteristics of laser weapons, speed of light engagement, precision targeting, rapid shot generation and tunability, offer the opportunity for expanded engagement options. These features can enhance the ability of naval units to defeat large raids and to counter short time-of-flight threats such as rockets, mortars and artillery shells. Speed of light engagement allows the MLW to address maneuvering platforms and weapons.

> . . . . laser weapons enable delivery of scalable levels of energy at both tactically and strategically relevant distances enabling the accomplishment of new missions and generating entirely new classes of effects during naval battle engagements and on the battlefield. They also offer unique solutions to many of the most serious threats and enable safer accomplishment of hazardous missions. Compared to traditional weapons, laser weapons offer significant benefits including: non-lethal, long-range force

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[14] Mark Gunzinger and Chris Dougherty, *Changing the Game: The Promise of Directed Energy Weapons,* Center for Strategic and Budgetary Assessments (Washington, DC, 2012), p. 23.

[15] Robert O. Work and Shawn Brimley, *20YY:Preparing for Warfare in the Robot Age,* Center for a New American Security (January 2014), p. 27.

> application capabilities, lethal target effects, potentially unlimited magazines and significantly smaller logistics footprints than non-DE weapon systems; although some specialized support equipment will be required. Furthermore, there are advantages of reduced operational costs and lower manpower requirements because of automated battle management systems using state-of-the-art electronics.[16]

Because their output power can be varied, a MLW also can conduct a variety of other operations. The MLD program showed the ability to use the solid-state laser to conduct intelligence, surveillance and reconnaissance missions. It is reasonable to assume that most of the time the laser system would operate as a high-fidelity electro-optic/infrared (EO/IR) sensor. The EO/IR capability of a laser weapon provides a huge advantage for the Strike Group Commander. Further, if an EO/IR search system were employed as part of a MLW system, the Strike Group Commander would have a passive search, track and kill weapon that does not exist in the surface force today. Laser optics can be employed for high-resolution target identification and tracking. An EO/IR capability with algorithms designed to identify, categorize and assign threat status allows the Strike Group Commander to make better rules of engagement (ROE) decisions.

Because laser power is adjustable this allows options beyond a kill, such as the ability to warn, distract and disable. Even a relatively low-power laser can be effective against electro-optical sensors. Unmanned threats can be disabled by destroying their cameras or optics vice shooting down the vehicle; again, providing the Strike Group Commander options in a sensitive diplomatic environment. This is of particular value in a highly cluttered environment or in the presence of small, maneuvering targets (e.g., small boats and UAVs). In addition, the MLW has the potential to be employed as a non-lethal disabling device against certain target classes.

When operating as an EO/IR system, the laser would require only minimal ship's power. This is what differentiates the laser from other high power systems and what makes it ideal for an energy storage medium like a battery. The battery can be recharged over the duty cycle from available ship's power. In principle, three Tesla batteries would provide sufficient power for the 100 kW laser two-minute firing time.

Most significantly, MLWs offer the prospect for addressing the challenges posed by both attacks employing limited numbers of advanced anti-ship missiles and those using large numbers of relatively simple, low-cost platforms and weapons. One of the best descriptions of the potential for maritime directed energy weapons to transform naval combat is provided in a paper by Ronald O'Rourke of the Congressional Research Service:

> Compared to existing ship self-defense systems, such as missiles and guns, lasers could provide Navy surface ships with a more cost effective means of countering certain surface, air, and ballistic missile targets. Ships equipped with a combination of lasers and existing self-defense systems might be able to defend themselves more effectively against a range of such targets. Equipping Navy surface ships with lasers could lead to changes in naval tactics, ship design, and procurement plans for ship-based weapons, bringing

[16] Captain David H. Kiel, Commander Michael Ziv, and Commander Frederick Marcell (Ret), *A Vision for Directed Energy and Electric Weapons In the Current and Future Navy*, http://www.wired.com/images_blogs/dangerroom/files/asne_paper_a_vision_for_de_weapons.pdf (n.d.).

about a technological shift for the Navy -- a "game changer" -- comparable to the advent of shipboard missiles in the 1950s.[17]

The introduction of an effective MLW would offer the potential to change the Navy's CONOPS for A2/AD environments. Laser weapons would provide an additional layer of defense with the potential to address "trash targets," thereby saving kinetic weapons for more severe threats. U.S. forces could engage these threats while holding back high cost, highly capable long range (over the horizon) weapons for a potential second or third wave assault by the enemy using their more advanced weaponry. Without a low cost weapon such as lasers, U.S. forces will waste their highly capable and costly advanced weapons against low cost threats early in a campaign placing themselves at a significant disadvantage due to requirements to resupply, which leads into the area denial issue.

Missile engagement doctrine will need to be reassessed with a weapon system this capable against in the horizon threats. A combination of laser and kinetic weapon systems would create a layered defense, permitting incoming threats to be preferentially engaged. A reevaluation of missile engagement doctrine not only saves money, but allows warfighters the options to evaluate how they will load out their magazines. Warfighters can shift from having to allocate a significant portion of cells for defensive weapons and allow limited cell space to be used for more offensive weapons such as Standard Missile (SM)-6, Tomahawk and SM-3. This will allow kinetic weapons to engage over the horizon, high speed, advanced threats and lasers to be used for close in defense. Lasers will not eliminate the need for kinetic weapons, but allow greater "engagement flexibility" to the warfighter.

A 250-500 kW MLW is what appears to be required in order to engage cruise missiles, aircraft and even ballistic missiles.[18] At these higher power levels, MLWs would support a modified shot doctrine and missile load flexibility. Taken together, these features would support the ability of naval platforms to operate in severe A2/AD environments, such as that being created by the People's Republic of China, for longer periods of time and address larger sizes of attack weapons.

By employing the massive power-generation capabilities of some classes of modern Navy ships, MLWs hold the prospect of bending, if not breaking the disadvantageous cost-exchange ratio between adversaries' anti-ship capabilities and the Navy's current suite of defensive systems. Navy air and missile defense interceptors cost between $1 million and $10 million apiece. In contrast, reliance on shipboard power generation allows the solid-state MLW to operate at a dollar per shot or less. Moreover, even if the magazines of surface combatants such as Arleigh Burke DDGs are totally devoted to the defense mission, there is the potential for the defense to be overwhelmed. An MLW connected to shipboard power generation systems theoretically would have a very deep magazine. Complementing the array of kinetic and electronic defensive measures available to naval combatants, MLWs would support a more efficient allocation of all resources, most significantly, relatively expensive air and missile interceptors.[19]

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[17] Ronald O'Rourke, *Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress*, R41526, Congressional Research Service (June 27, 2013), p. 1.
[18] *Ibid.*, pp. 7, 37. Also, Mark Gunzinger, *op. cit.*, pp. 13, 26.
[19] Mark Gunzinger, *op. cit.*, p. 3.

The current Navy laser program provides an opportunity to accomplish more than just enhance the effectiveness of shipboard defenses. It is the beginning of a process by which the U.S. military stops playing defense with respect to the emerging A2/AD threat and imposes costs and problems on U.S. adversaries. An operational MLW will force adversaries to consider complicated and, more important, expensive measures in order to counter the defense's effectiveness. MLW should be viewed as part of an integrated package of investments including manned and unmanned aerial platforms, enhanced air and missile defense interceptors, improved electronic warfare, cyber weapons and signature modification techniques intended to allow the Navy to maintain assured access to contested waters.

Rear Admiral Thomas Rowden, Director, Surface Warfare Division, sees directed energy as a critical part of a comprehensive mid-term strategy (on the order of 10 years from today) to use advances in a host of technologies to defeat the A2/AD threat.

> Electronic warfare improvements, increased laser capabilities, more capable gun projectiles, and a return to Cold War-era electronic warfare concepts of operation will improve the currently unfavorable cost/exchange ratio between increasingly inexpensive and capable threat missiles and our very capable—and expensive—interceptors. We will work to decrease the cost per engagement, in some cases with less expensive hard kill systems, in others with active or passive electronic warfare measures. Ensuring our ability to remain within any contested battle space is critical to the success of any major maritime operation.[20]

The Maritime Laser Demonstrator successfully disabled a small target vessel using a solid-state, high-energy laser mounted on the deck of a Navy test ship.

The Navy has already conceptualized what kind of module might be inserted into the current variant of the Burke-class destroyer to support high-power solid-state lasers. But it isn't useful to build or modify only a few destroyers with laser weapon capabilities; the capability needs to be proliferated across the fleet once it is integrated and tested. New warships should be wired to accept lasers as a drop-in capability, and the equipment needs to be affordable. Also, sailors need to be socialized to the operational features of the new weapon.

Admiral Greenert has a vision of a future Navy that is based on exploiting a range of new technologies and capabilities. This image was summarized in a single sentence in the speech he gave at the christening of the USS *Gerald R. Ford*, the first of a new class of nuclear powered aircraft carriers. The *Ford* is a revolution in aircraft carrier design and capabilities with an advanced nuclear power plant that will generate enormous amounts of energy, an electromagnetic aircraft launch system, a new radar suite, extensive automation and an innovative arresting gear system. In describing the role of the new Ford-class carriers, Admiral

[20] Rear Admiral Thomas Rowden, "U.S. Navy, Building the Surface Fleet of Tomorrow," *Proceedings*, Volume 140, Number 1 (January 2014), p. 5.

Greenert provided his listeners with a vision of the future for his service, saying, "She will carry unmanned aircraft, joint strike fighters, and **she will deploy lasers**." *(Emphasis added).*[21]

Next Steps

The Navy's effort to deploy an effective MLW is directed at addressing critical capability gaps, particularly those related to the emerging A2/AD environment.

> Given the surface fleet's ability to overcome the technical challenges associated with the military exploitation of high power, long range DEW *[Directed Energy Weapons]* -- including power, cooling, weight, and volume requirements -- it is the logical vanguard for demonstrating the potential of first-generation weapons. Across the spectrum of DEWs, early applications will focus on supporting forward deployed forces to defeat Improvised Explosive Devices (IEDs); artillery, mortars, and rockets; intelligence, surveillance and reconnaissance systems; fast-attack craft; fixed and rotary-wing aviation; and subsonic anti-ship cruise missiles. The longer term objective is to field higher power systems capable of defeating supersonic cruise missiles and selected ballistic missiles.[22]

The first step for the Navy is to undertake and successfully complete its currently planned experiments. It is critical that the planned development and testing of a prototype MLW successfully demonstrate the ability to operate the system under realistic conditions and to address not only technical issues such as beam quality and jitter, but lingering concerns about the effect of environmental factors that could limit the effectiveness of a directed energy weapon.

The USS *Ponce* deployment also is intended to identify and resolve CONOPS, tactical and "cultural" issues associated with the employment of this transformational capability. One goal of this demonstration must be to address barriers to transition such as predictive avoidance, collateral damage, rules of engagement and policy.

The Navy's SSL-TM program is designed to achieve a successful prototype laser weapon deployment in 2014 and the scaling up of the prototype to the point that it would serve as the basis for the initiation of a program of record in 2016. According to a recent report on naval lasers by the Congressional Research Service:

> If the LaWS effort were converted soon into a POR *[Program of Record]*, the Navy believed a production version of LaWS might achieve Initial Operational Capability (or IOC -- a type of official in-service date) on Navy surface ships around FY2017. The Navy estimated that production copies of the LaWS system could be installed and

[21] Admiral Jonathan Greenert, speech, http://www.navy.mil/navydata/people/cno/Greenert/Speech/131109 USS Ford Christening.pdf (November 9, 2013).
[22] Department of the Navy, *A Directed Energy Vision for U.S. Naval Forces*, cited in Ronald O'Rourke, *op. cit.*, p. 18.

procured as additions to ship CIWS *[Close In Weapon System]* mounts for a total cost of roughly $17 million per CIWS mount.[23]

In 2007, the Defense Science Board recommended that the defense department integrate and focus its fragmented array of directed energy programs. In addition, the DSB proposed focusing science and technology efforts on high-power solid-state and fiber optic lasers and significantly improved power generation and beam control with a particular emphasis on addressing the challenge of ship defense.[24]

Significant progress has been made in the priority areas identified by the DSB. The pace at which power generation and beam control for solid-state lasers has advanced is nothing short of amazing. A 100-150 kW laser appears within relatively easy reach. By 2020, it should be possible to demonstrate a 250-500 kW laser weapon system, one appropriate for deployment on current surface combatants and capable of being a game changer in the Navy's struggle to address the growing A2/AD challenge.

The Navy is to be commended for leading the charge in directed energy weapons, specifically the first deployment of LaWS on the *Ponce* in Fifth Fleet, breaking legal ground with ROE and Geneva Convention analyses, single operator employment, Aegis Combat System integration, warfighter support and advocacy and predictive avoidance solutions. The Navy still needs to take some additional straightforward steps to transition this technology from science and technology to a formal program of record.

- Establish an appropriate funding line as part of POM16 to support a program of record;
- The Office of the Chief of Naval Operations (OPNAV N96) needs to define the requirements for DE weapons on ships. The problem of dealing with the threats posed by fast attack craft and hostile UAVs is already well recognized. ONR has already written a draft Capability Development Document and provided a detailed weapon specification for the SSL-TM;
- Tailor the acquisition process for a Milestone B decision in 2016. The technology development phase for a laser weapon is in progress: LaWS will be operationally deployed in 2014 and SSL-TM will be demonstrated at sea in 2016/2017 at Technology Readiness Level 6+. Lasers are ready for the engineering and manufacturing development phase now;
- Pursue the necessary research and engineering into DE enabling technologies such as power management, storage and system cooling;
- Move rapidly to develop and demonstrate a laser weapon in the 150 kW range as a prelude to meeting the likely requirement for a 250-500 kW weapon system; and
- Begin to develop a detailed plan to backfit 250-500 kW DE weapons into DDG-51 Flight II, design and integrate 250-500 kW DE weapons into the new DDG-51 Flight III, and design and integrate a 125 kW laser mission module for the Littoral Combat Ship. This means developing the architecture for shipboard power generation/management/cooling,

[23] Ronald O'Rourke, *op. cit.*, p. 10.
[24] Defense Science Board, *op. cit.*, p. iv.

addressing design issues associated with placing aboard ship the topside beam director and interior power system and integration of the weapon with shipboard systems.

It is clear that directed energy weapons are no longer just science experiments. They have been successfully demonstrated and tested repeatedly. It is time to move towards actual weaponization and deployment. The go-slow, take-small-steps, wait-and-see approach works okay for research organizations and government labs in general, but it is not adequate for the creation of a new generation of military capabilities. Nor is the current approach likely to entice industry to invest scarce corporate resources in this area.

The requirement for a transformational capability such as the MLW is clear. Progress on the technology has been significant; with the completion of the prototype MLW system the technology readiness level for the critical technologies will be a seven out of ten. The *Ponce* deployment and the simulation exercise should help to resolve many of the outstanding employment, operational and policy issues. Given the Navy's clear need for directed energy weapons and anticipating continuing progress across all these fronts, should the ongoing technology development efforts mature, the Navy needs to be prepared to rapidly transition to a program of record.

Appendix A. International Directed Energy Programs

The United States is not alone in pursuing directed energy (DE) weapons. The Soviet Union has worked for years to develop a range of weapons for tactical and operational employment. A facility at the Sary Shagan testing range was believed to be for a large laser capable of "blinding" satellite sensors. There are reports that the Soviet military had by 1980 deployed tactical lasers capable of interfering with optical sensors. Finally, Moscow had an active airborne laser program with two test bed aircraft deployed by the late 1980s.[25] With the fall of the Soviet Union, these programs were essentially dismantled.

In recent years, the effort to exploit directed energy for industrial as well as military purposes has accelerated. A number of countries, some allies of the United States and others not, are developing directed energy weapons.

1. China

Western reports make it clear that the People's Republic of China has a serious DE weapons program. As far back as the mid-1990s, it was reported to have developed and marketed the Chinese ZM-87 military laser interference device, a tripod-mounted battlefield laser dazzler.[26] Priorities include development of chemical and solid-state laser technologies to ultimately field a weapons-grade system from ground-based and airborne platforms.[27]

The Beijing Institute of Remote Sensing Equipment is reported to be working on laser weapons as well as missile guidance systems. The Institute's Director, Li Hui, has cited laser technology as the only effective means to counter cruise missiles. According to published reports, Li Hui has "encouraged the acceleration of laser weapons development," while stressing that an "anti-cruise missile laser weapon" already developed by China "utilizes...the most mature high-energy laser technology, the deuterium-fluoride (DF) chemical laser."[28]

According to publicly available documents, Chinese assessments of military technologies identify directed energy weapons as having the potential to dramatically influence the future of warfare.

> The 1028th Research Institute (RI) of the Ministry of Information Industry, a major Chinese developer of integrated air defense systems, has analyzed the use of lasers in future warfare. Such uses include active jamming of electro-optics, blinding combatants

[25] Steven J. Zaloga, "Red Star Wars," *Jane's Intelligence Review* (May 1, 1997). Dr. Carlo Kopp, *High Energy Laser Directed Energy Program*s, Airpower Australia (May 2008). Dwayne A. Day and Robert G. Kennedy III, "Soviet Star Wars: The launch that saved the world from orbiting laser battle stations," *Air & Space Magazine* (January 2010). Sam Marsden, "Soviet military 'had laser weapons for use against NATO forces in 1980s,'" *The Telegraph* (August 1, 2013).
[26] Alane Kochems and Andrew Gudgel, "The Viability of Directed-Energy Weapons," *Backgrounder*, No. 1931, The Heritage Foundation (April 28, 2006).
[27] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2013*, Annual Report to Congress (2013).
[28] [[missing citation]]

and damaging sensors, causing laser-guided weapons to deviate from their true targets, and target destruction.

The appearance of laser weapons will have a significant impact on modern warfare. On today's electronic battlefield, it is natural for defensive systems to use low-energy laser weapons to damage enemy electronic equipment. When high-energy lasers that can directly destroy tanks, planes and ships develop and mature, they will be formidable offensive weapons.[29]

2. Europe

Europe is making progress in the application of directed energy technologies for science, manufacturing and defense. The European Extreme Light Infrastructure (ELI)-Beamlines science facility in the Czech Republic, like the European Organization for Nuclear Research (CERN) supercollider facility, will be an international center for advanced laser research. The ELI will be the world's most powerful laser. The Lawrence Livermore Nuclear Laboratory is collaborating with FEMTOLASERS Produktions GmbH in the design and development of the ELI system.

Rheinmetall has fielded a prototype directed energy weapon. The company's Live Laser Demonstration 2013 included fielding of three vehicle mounted tactical lasers as well as fixed laser weapon systems. According to the company, a high point of the demonstration came with the successful engagement of a swarm of jet-powered drones.

In October 2012, MBDA Systems' German subsidiary used its 40 kW system to shoot down airborne artillery from a distance of 2 km. The 40 kW system was built with four 10 kW sources provided by industrial fiber laser maker IPG Photonics.[30]

3. Israel

Even as Israel has deployed ever more sophisticated defensive technologies, its enemies have not given up on the use of missiles and rockets. Their offensive counter to Israeli missile defenses has taken two forms. The first is to massively increase their holdings of ballistic missiles and rockets hoping simply to inundate Israeli defenses or run them out of interceptors. The second is to improve the guidance on their larger and longer-range rockets and missiles making them more likely to find their target and thereby forcing the defense to engage each and every incoming weapon.

The U.S. and Israel have been working on laser-based defenses for more than a decade. As far back as 2004, the chemically-powered Tactical High Energy Laser system successfully engaged and destroyed missiles, rockets, artillery projectiles and even very small mortar shells fired singly and in salvoes.

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[29] "China Advancing Laser Weapons Program," Asian Defence News, http://www.asian-defence.net/2011/07/china-advancing-laser-weapons-program.html (n.d.)
[30] "MBDA's laser weapon destroys artillery models," *Optics.org* (November 14, 2012).

In the latest cycle of the offense-defense dynamic, there are reports that Israel is planning to add directed energy weapons to its array of missile defense capabilities. There are reports that a system called the "Iron Beam" will be deployed to better counter the very short-range/short flight time rockets being fired from the Gaza Strip. Although details about the Iron Beam system are lacking, it probably is a relatively low-power solid-state laser weapon, with as few as 10 kW of power. However, Israeli sources report that their plan is to move to several hundred kilowatts in the future.[31]

4. India

According to the Director of the Indian Defense Research and Development Organization (DRDO), India has the capability to build anti-satellit**e** weapons but has no plans for any activity that affects the peaceful use of space. This includes the use of directed energy systems to pinpoint a target. The Director also stated that his organization was working on converging technologies concerning high energy systems. The Laser Science and Technology Center at the DRDO is reported to have developed a portable dual-role electro-optical countermeasure laser system suitable for both anti-sensor as well as dazzling applications with an operational range of 2.5 km.[32]

5. Japan

Japan has a number of centers that are developing lasers for scientific and industrial applications including the X-ray Free Electron Laser facility, the Kunioki Mima Institute of Laser Engineering at Osaka University, the Advanced Photon Research Center of the Japan Atomic Energy Research Institute and the NADEX Laser Research Center.

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[31] Gareth Jennings, "Singapore Airshow: Rafael launches Iron Beam," IHS Jane's Defence Weekly (February 10 2014).

[32] "India has capacity to make anti-satellite weapons: DRDO chief," http://news.webindia123.com/news/Articles/Science/20140207/2335887.html (2014). Rajat Pandit, "DRDO's next: Star Wars-like Weapons," *The Times of India* (August 3, 2010).

Appendix B: Glossary of Terms

A2/AD	Anti-Access/Area Denial
ABL	Airborne Laser
ADAM	Area Defense Anti-Munitions
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CERN	European Organization for Nuclear Research
CIWS	Close In Weapon System
CONOPS	Concept of Operations
DDG	Guided Missile Destroyer
DE	Directed Energy
DEW	Directed Energy Weapons
DoD	U.S. Department of Defense
DRDO	Defense Research and Development Organization
DSB	Defense Science Board
ELI	Extreme Light Infrastructure
EMALS	Electro-Magnetic Aircraft-Launch System
EO	Electro-Optical
HEL MD	High Energy Laser Mobile Demonstrator
IED	Improvised Explosive Device
IOC	Initial Operational Capability
IPS	Integrated Power Systems
IR	Infrared
IRGC	Islamic Revolutionary Guard Corps
km	Kilometer
kW	Kilowatt
LaWS	Laser Weapon System
MLD	Maritime Laser Demonstrator
MLW	Maritime Laser Weapons
ONR	Office of Naval Research
PLAN	People's Liberation Army Navy
POM	Program Objective Memorandum
POR	Program of Record
R&D	Research & Development
ROE	Rules of Engagement
SM	Standard Missile
SSL-TM	Solid State Laser Technology Maturation
THEL	Tactical High Energy Laser
UAV	Unmanned Aerial Vehicle

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