Report of the

High Energy Laser Executive Review Panel

Department of Defense Laser Master Plan

March 24, 2000

DoD/S&T/00-001/March 24, 2000

DEPARTMENT OF DEFENSE LASER MASTER PLAN

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EXECUTIVE SUMMARY

Introduction

This report is the result of a DoD initiative intended to capitalize on the significant advancements in High Energy Laser (HEL) technology during the past decade and to focus the Department's HEL investment strategy on the emerging national security needs of the 21st century. It also responds to the Congressional requirement for a Laser Master Plan, as defined in Section 251 of the National Defense Authorization Act for Fiscal Year 2000, that addresses the following:

- Potential weapons applications of chemical, solid state, and other lasers
- Critical technologies and manufacturing capabilities required to achieve such weapons applications
- A developmental path for critical technologies and manufacturing capabilities
- Management and oversight
- Funding

The report is the product of a committee of government experts, chaired by the Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T)). The committee was chartered to review all Research, Development, Test and Evaluation (RDT&E) activities relevant to the future development of HEL weapon systems. The principal findings and recommendations are provided below and discussed at length in the body of the report.

Findings

1. HEL systems are ready for some of today's most challenging weapons applications, both offensive and defensive.
2. HEL weapons offer the potential to maintain an asymmetric technological edge over adversaries for the foreseeable future.
3. Funding for HEL Science and Technology (S&T) programs should be increased to support priority acquisition programs and to develop new technologies for future applications.
4. The HEL industrial supplier base is fragile in several of the critical HEL technologies and lacks an adequate incentive to make the large investments required to support current and anticipated Department of Defense (DoD) needs.
5. The DoD should leverage HEL relevant research being supported by the Department of Energy (DOE) and other government agencies and also by commercial industry and academia.
6. It is increasingly difficult to attract and retain people with the critical skills needed for HEL technology development.

Recommendations

Based on the findings, the Panel recommended the following specific actions:

1. *DoD should implement a new management structure for HEL technologies*.

   A Department-wide, coordinated investment and execution strategy is necessary to take advantage of opportunities presented by HEL weapons technologies. This requires a new management structure whose central feature is a Joint Technology Office (JTO), tasked with the development and day-to-day management of a joint program for revitalizing HEL S&T and serving as a clearinghouse for new S&T initiatives proposed by DoD components. The JTO should have an SES-level Director who reports to the DUSD(S&T) and a military support staff whose members will also serve as liaison officers for their respective Service. Technology Area Working Groups, composed of representatives from all DoD stakeholder organizations, would support the JTO in developing detailed technology roadmaps. Additionally, the JTO should maintain a Technology Alliance to foster information exchange and cooperative activities with other government organizations, universities, and industry. Senior level oversight of the JTO would be accomplished through a Technology Council and a Board of Directors. The Technology Council, which should be chaired by the DUSD(S&T) with a membership that includes the Senior S&T Executives from the Services, DARPA, BMDO and DTRA, will review and prioritize the technology programs proposed by the JTO and make funding recommendations. The Board of Directors, which should be chaired by the Under Secretary of Defense, Acquisition, Technology and Logistics (USD(AT&L)) with the Director, Defense Research and Engineering (DDR&E) serving as Vice Chairman and a membership that includes the Service Acquisition Executives (SAEs), and the Directors of DARPA, BMDO and DTRA, will review and validate the S&T funding recommendations in the context of Department-wide HEL programs.

2. *DOD should increase funding allocated to HEL S&T to achieve a better balance between large demonstration programs and enabling S&T programs.*

   The Department currently funds HEL technology almost exclusively via large demonstration projects. Programs such as the Air Borne Laser (ABL), Space Based Laser (SBL), and Tactical High Energy Laser (THEL) are desirable to demonstrate that HEL weapons can be fielded, but they consume large amounts of DoD funding. There must be a corresponding level of S&T funding to ensure the future growth of these programs and to underwrite the success of other HEL-based weapons systems. All supplemental S&T funding should be allocated to a Program Element (PE) assigned to the Joint Technology Office for competitive distribution to S&T priorities. Absent new funding, the present imbalance between HEL demonstrations and S&T should be corrected through a reallocation of total S&T funding.

3. *DoD should stimulate the HEL industrial supplier base with focused investments.*

The Department will not be able to field HEL weapons if the supplier base continues to decline or if universities do not produce enough graduates with the skills or motivation to work in this area. A few well-directed program initiatives could stimulate development of promising new technologies and at the same time create a demand for essential skills.

4. *The DoD should investigate the potential for cooperative programs with the DOE and other government agencies, industry, and academia.*

   The DoD should take advantage of the significant investments and capabilities resident in DOE laboratories and elsewhere. The panel strongly endorses DoD initiatives to pursue collaborative arrangements and to leverage their research programs through mutually beneficial activities.

Conclusions

Together, the recommendations comprise a restructured perspective in developing HEL weapons. Developing revolutionary capabilities in HEL weapons requires a coordinated and focused investment strategy under a new management structure, featuring a Joint Technology Office with senior-level oversight provided by a Technology Council and Board of Directors. Any new investment strategy must also recognize the need to achieve a better balance between large demonstration projects and enabling S&T projects. Currently, about 70% of the total HEL S&T funding is dedicated to large-scale system demonstrations. In the future, a better balance could be achieved by transitioning large demonstration projects to non-S&T accounts sooner than has been done in the past. For the present, either new S&T funding must be identified, or at a minimum, the present imbalance between integrated demonstrations and S&T should be corrected through a reallocation of total S&T funding. The Panel recommends that the Office of the DUSD(S&T) submit an input to the FY2002 Program Objective Memorandum (POM) for enhanced HEL S&T funding. While recognizing the importance of system demonstration projects, the Panel also strongly recommends that a reprogramming be considered for FY2000 and FY 2001 to meet the immediate needs for HEL S&T.

DEPARTMENT OF DEFENSE LASER MASTER PLAN

Introduction

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The report is the product of a committee of government experts, chaired by the DUSD(S&T). The committee was chartered in September, 1999 by the USD(AT&L) to review all Research, Development, Test and Evaluation (RDT&E) activities relevant to the future development of HEL weapon systems. The High Energy Laser Executive Review Panel (HELERP) held five meetings in Washington, D.C., and two meetings in conjunction with laser facility tours in California and New Mexico (see Appendix B). The Panel findings and recommendations are based on detailed reviews of existing laser programs, site visits to major industry and government facilities, discussions with government and industry experts in the field, and deliberations among the Panel members.

To facilitate the timely completion of the report, the HELERP commissioned Working Groups (WGs) in six key technology areas.

- Chemical Lasers
- Solid State Lasers
- Free Electron Lasers
- Beam Control
- Lethality
- Advanced Technology

The WGs were composed of government personnel who received numerous briefings from industry. Each WG met several times apart from the Panel and developed roadmaps tailored to these principal technology areas. Detailed WG reports will be compiled as a companion Volume to this report, but highlights are summarized here. Findings and recommendations are deliberately broad, with the intent of providing an overarching framework to guide DoD's investment strategy for HEL programs.

Background

To provide a basis for the discussions that follow, a brief description of HEL systems is presented here, along with definitions of terms commonly used in the field.

Building a HEL weapon system requires more than simply providing a laser device with a specific power level. It also requires a means for getting the laser power out of a beam director toward the target in such a way that the laser beam can deliver a lethal fluence on the target. (Fluence is the energy per unit area deposited by the laser on the target.) The laser energy must couple efficiently to the target, and it must exceed some failure threshold that is both rate-dependent and target-specific. Figure 1 depicts the elements typically included in a HEL weapon system. They include the laser device, a "local loop" or beam transfer system, a "target loop" which ensures that the beam delivers its punch to the target, a propagation stage, the target coupling, and the lethality mechanism associated with the laser.

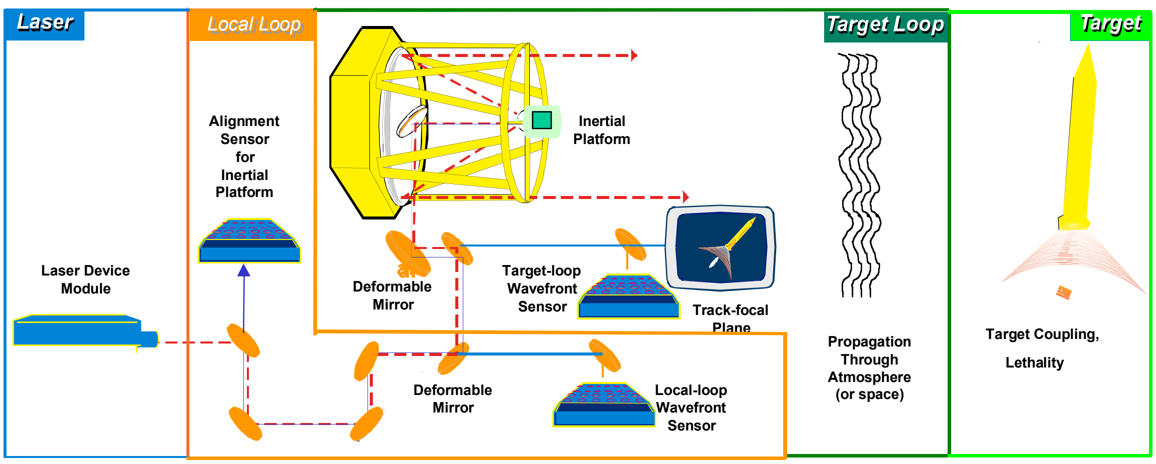

Figure 1. Schematic diagram of a HEL weapons system.

The laser device produces high-energy light at a particular wavelength (or small set of wavelengths). Different device technologies will produce widely different power levels and beam quality. Beam quality is a measure of how effective the laser is in putting its light into a desired spot size at the target. It has a minimum value of one, with higher values indicating that the light is spread over a larger area than a diffraction-limited laser (a laser with perfect optics) would produce. For HEL weapons, good beam quality is frequently as important as high power. (One HELERP task was to predict which technologies have the potential to produce the desired power/beam quality combinations in the future, at a reasonable cost. If lasers are to be fielded, then it is imperative that the selected technology efforts deliver their promised power and beam quality figures of merit within budget and on schedule.)

DoD currently funds three kinds of laser device technology for High Energy Laser Weapons: Chemical, Solid-State and Free Electron. Chemical lasers produce their energy from excited atomic or molecular species produced by chemical reactions. Weapon class chemical lasers include hydrogen and deuterium fluoride (HF and DF) and chemical oxygen/iodine lasers (COIL). These devices have achieved Megawatt-class power levels and simultaneous good beam quality. Solid-state lasers include heat capacity, fibers and continuously-cooled lasers. In the past, flashlamp-pumped solid-state lasers have produced high peak power, at the kilowatt level with good beam quality. However, it is the development of high efficiency, laser diode arrays that enables the possibility of higher average power solid-state laser weapons. Free electron lasers produce their energy by passing a relativistic electron beam through a structured magnetic field. Electrons accelerated during passage through a magnetic field create the optical radiation. These devices have also produced kilowatt-class output with good beam quality. Each of the device types has limitations, such as the limited magazine size of current chemical lasers, the strong thermal management and power supply requirements of current solid state lasers, and the large size and weight of current free electron lasers. S&T efforts in each technology are principally dedicated to solving those problems.

Once the device has produced high power, the energy must be transmitted to the target. The laser beam must first be directed through a local control loop, which allows the weapon user to execute positive control on the beam. Safe operation of weapons systems is essential, and the local loop accomplishes that function along with any needed beam cleanup functions. The target control loop is the portion of the weapon system that acquires and tracks the target, directing the laser beam to a particular place on the target in order to destroy it. For some systems, the target loop can be extremely complicated, such as when measuring and correcting for optical aberrations induced by the atmosphere. The local and target loops are the locations of all the Beam Control functions in the HEL weapon system.

The laser weapon system produces as clean and powerful a beam as possible before unleashing it toward the target. Typically, a beam director or telescope is the last element the beam sees before it begins its propagation to the target. The propagation can be in free space or in the atmosphere. If it occurs in the atmosphere, then turbulence, scattering, absorption (and associated thermal blooming) and other effects can strongly affect the quality of the beam. (Thermal blooming is an additional wave-front error caused by local heating of the atmosphere from the HEL itself.) DoD has developed revolutionary techniques for compensating for these effects as much as possible so that the propagation step takes a well-corrected beam to the target. Nevertheless, three fundamental parameters affect the beam on its way to the target:

- **Wavelength** – Shorter wavelength light is less affected by diffraction but can be more strongly affected by device optical imperfections, turbulence and other atmospheric effects.

- **Transmitter diameter** – A large transmitter is able to produce a small spot on the target when the beam is diffraction-limited, and conversely, a small transmitter can produce only a larger spot. Down to a certain target dependent limit, small spots are desirable because they have higher irradiance (power density) and can be more lethal to a target.
- **Range** – The distance of the target from the HEL weapon system is a critical parameter that strongly influences system design. Destruction of distant targets requires much tighter beam control tolerances and more disciplined system engineering design.

During propagation through the atmosphere, molecular constituents and air density cause scatter and absorption. Absorption can initiate thermal blooming if the power density is high enough, and air density and thermal gradients cause turbulence. These effects attenuate and spread the beam, and the effects are considerably worse near the surface of the earth than at high altitudes.

Even if the HEL weapon system produces a bright irradiance at the target, there must be a strong coupling of the laser light to the target in order to produce damage. The coupling is a function of the wavelength of the laser, the materials composing the target, and the aspect angle that the target presents to the beam. Thus, it is more difficult to destroy a missile that is heading nose-on to the beam because the nose can be made hard to radiation. It is much easier to destroy a missile that presents more of a broadside view to the beam, since it is then possible to place the laser energy on the most vulnerable part of the missile. There are several such considerations the weapon designer must evaluate in designing a weapon against a class of targets. For example, high absorption (low reflectivity) is desired for the HEL laser to increase the coupling to the target, but high reflectivity is desirable for some beam control functions. Lethality assessments require good information about the target, such as where it is likely to be most vulnerable.

Findings

While the Panel was not unanimous on all points, the following discussion represents majority opinions.

Finding 1: HEL systems are ready for some of today's most challenging weapons applications, both offensive and defensive.

There has been considerable discussion in the Defense community regarding the applicability of HEL for weapons applications. In principle, these weapons can be used in either offensive or defensive applications, though the predominant role has been defensive. For example, the Air Force Air Borne Laser (ABL) program is designed to defend against Theater Ballistic Missiles (TBM) in a tactical war scenario. Similarly, the Ballistic Missile Defense Organization (BMDO) and the US Air Force (USAF) jointly manage and fund the Space Based Laser (SBL) project to develop technology for destroying both Inter-Continental Ballistic Missiles (ICBM) and TBMs. The Army Tactical High Energy Laser (THEL) program is currently testing a laser to defend against rockets and other tactical weapons.

To help define whether HEL weapons are ready for system applications, the Panel defined applications concepts that the working groups could use to score competing technologies. The guidelines given to the working groups were straightforward:

- Concentrate on unique attributes of HEL weapons
  - ✓ Ability to address high speed and highly maneuverable targets
  - ✓ Ability to deliver lethality at the speed of light - Targets requiring short reaction time (compressed battlefield applications)
  - ✓ Ability to produce graduated thermal effects – Less than lethal applications
- Use the laser weapon to stimulate target-induced destruct mechanisms such as rupturing pressurized tanks on liquid fueled missiles
- Include only systems that are of interest to warfighters

Laser weapons applications can be divided into defensive and offensive categories, and the weapon can be evaluated using mission-specific engagement parameters. The Panel developed seven missions, or application concepts, for the working groups. A color ranking was used to help assess the difficulty of destroying the associated target. Yellow scores imply that the target is very difficult to kill with a HEL weapon (and in some cases, with any weapon), both in terms of lethality requirements and also in terms of the precision with which the HEL must be controlled. Green scores indicate moderately difficult targets, and blue scores indicate less difficult targets. For each application concept, the Panel defined the notional values of range, fluence, laser spot size, and magazine size (number of shots available) to assist the working groups in scoring their technologies. Figure 2 highlights the applications for which lasers may have a distinct advantage over other weapons concepts.

Offense or Defense	Application	Targets	Perceived Difficulty
Defense	National Missile Defense	Ballistic Missile	Y
	Theater Missile Defense	Ballistic Missile	G
	Area or Point Defense	Cruise Missile, Rockets, Aircraft	B
		Mortars, Artillery	Y
	Platform Defense	Cruise Missile	B
Offense	Airborne Precision Strike	Aircraft, Surface Craft	B
	Non-Lethal Weapons	Aircraft, Surface Craft	B
	Anti-Satellite	Satellites	G

Figure 2. Applications Concepts for HELERP Working Groups to Score Technologies. (Yellow – Very difficult to acquire targets, control HEL beam, and destroy targets; Green – Moderately difficult; Blue – Less Difficult)

Finding 2: HEL weapons offer the US the potential to maintain an asymmetric technological edge over adversaries for the foreseeable future.

Lasers have the potential to emerge as one of the principal weapons technologies underpinning US national security interests during the 21st century. Already, chemical lasers have been shown to be capable of delivering lethal amounts of energy against in-flight missile targets in engagement scenarios that severely stress current conventional intercept capabilities. Moreover, lasers offer the potential to meter out smaller bursts of energy as needed for highly discriminate lethal as well as non-lethal applications. DoD is increasingly faced with missions that require flexible response options to deal with an inferior but determined and recalcitrant adversary. Today's military commander desires the option to inflict non-lethal attacks prior to the use of lethal force. Lasers offer the potential of such intermediate response options as a complement to existing options involving the use of lethal force.

Finding 3: Funding for HEL Science and Technology (S&T) programs should be increased to support priority acquisition programs and to develop new technologies for future applications.

Due to diminishing resources, there is constant tension between the desire to develop new technologies for the warfighters and the need to maintain a high state of readiness and modernization in our acquisition programs. Keen competition for funds is reflected in the HEL S&T funding profile in Figure 3, which shows a precipitous decline in the mid-1980's and early 1990's, and a more gradual, steady decline in the future.

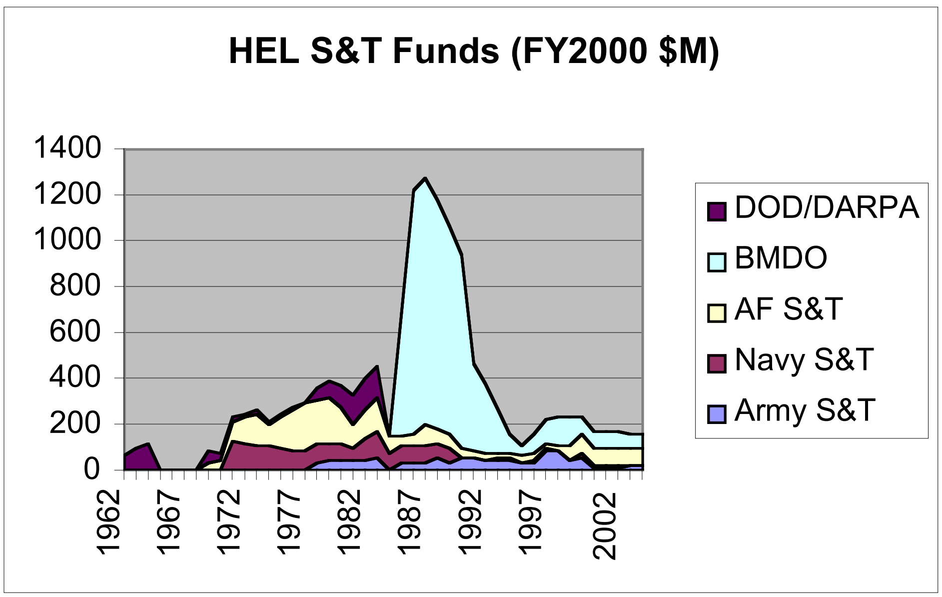

Figure 3. US funding (FY2000 dollars) in HEL S&T.

The current funding shortfall in HEL S&T is exacerbated by a tendency to fund large demonstration projects with S&T money. While these programs have considerable merit, there is an understandable tendency to stop developing a particular technology once the demonstration program has reached its designed level of performance. To illustrate, the Air Borne Laser (ABL) program has a particular required level of performance for illuminator power level and beam quality. Once the program manager determines that industry can provide a laser illuminator with that performance, there is little incentive to continue developing the illuminator laser technology. Such an action could have drastic consequences for future HEL needs. Today's illuminators are generally Solid State Lasers (SSLs). If S&T development on SSL illuminators is discontinued after a certain demonstrated level of performance, then there may be no means to continue to investigate the possibility of SSL for the HEL weapon itself. As a result, other programs that might use a high-power SSL for a HEL weapon in the 2010-2020 time frame will suffer from the lack of development of newer technology. A stable, robust S&T program should not be traded in favor of purely system-level demonstrations. A balanced approach should be pursued.

The S&T community in the Services has traditionally funded a technology base leading to new components or techniques somewhat independent of any program applications. Other agencies, such as the Defense Advanced Research Projects Agency (DARPA), have also contributed to the broad technology base but there are currently no DARPA efforts in HEL technologies. In today's HEL environment, DoD is funding large-scale demonstration systems but has devoted few resources to the technology base. This has significantly affected the Department's ability to do smaller projects to investigate a greater range of problems and solutions. Figure 4 contrasts, in a notional comparison, the current process to demonstrate HEL technologies with the preferred process for HEL weapons.

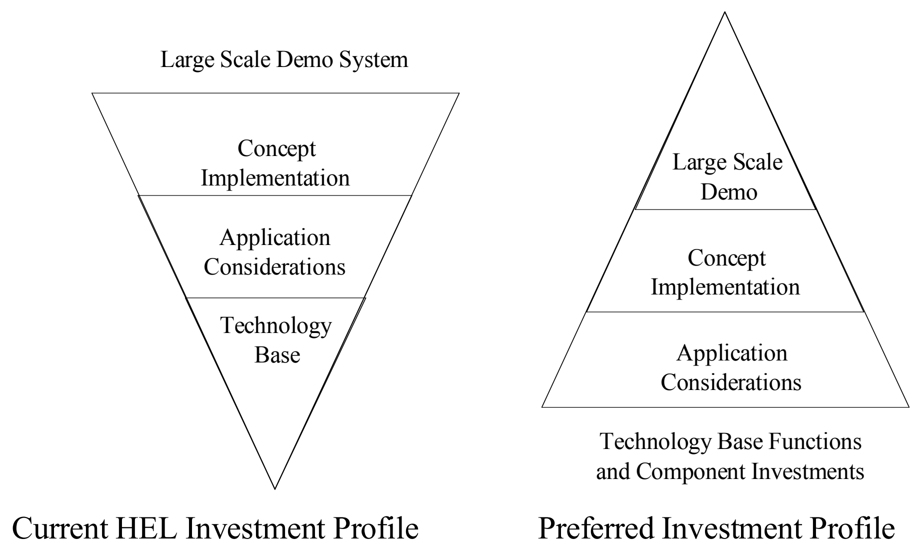

Figure 4. Notional comparison of investment profiles for HEL S&T development.

Finding 4: The HEL industrial supplier base is fragile in several of the critical HEL technologies and lacks an adequate incentive to make the large investments required to support current and anticipated DoD needs.

DoD research efforts have suffered from repeated S&T funding decreases. Moreover, numerous industrial suppliers have either consolidated or simply gone out of the business of supplying DoD with such HEL technologies as deformable mirrors and high-bandwidth, low-noise sensors. Since these technologies are essential for weapon-level applications of HEL, there is a strong possibility that the US will be unable to produce such weapons when they are ultimately needed.

To underscore this point, Table 1 illustrates how the US supplier base has declined from several or many suppliers to only one or two in several key component areas. In some cases, the single supplier is a small business. As a result, if the DoD elects to pursue several HEL programs simultaneously, the supplier base may not be able to meet the demand or offer a cost-competitive product.

Table 1. US industrial supplier base for key HEL components.

Major HEL Components	Prior Suppliers	Current Suppliers	Vendors
Laser Device	6	2	**TRW**, *Boeing*
Wavefront Sensors	3	1	*AOA*
Deformable Mirrors	4	1	*Xinetics*
Coatings	3	2	**Barr**, *OCLI*
Large Mirror Blanks	3	2	**Corning, Schott**
High Power Windows	2	1	**Heraeus**
Focal Plane Arrays (SWIR)	3	2	*RSC, Hughes*

BOLD-Stable Business Base, *Italics – Marginal HEL Base*
Source: ABL/GBL Technology Support Studies at AFRL

The lack of a DoD supplier base is especially troubling in view of the rapid advance of commercial applications of lasers in communications, material processing, cutting, welding, and low-power sensing. The commercial world is willing and able to pursue the necessary technology for these relatively low-power applications. But when it comes to high-power, weapon-grade applications of lasers, DoD has unique requirements above and beyond the commercial needs. Yet the volume of DoD's unique needs is not enough for industry to maintain technology base and sustain a reasonable profit margin. It is therefore not surprising that the overall DoD supplier base for HEL weapons is small and declining.

One generally unrecognized casualty of the lack of DoD-funded research efforts is the spin-off of DoD technologies to commercial and medical applications. For example, solid state laser diode fabrication S&T in the 1980's and 1990's produced major improvements in manufacturing efficiency, thus keeping the solid state laser diode industry alive and healthy in the U.S. Also, adaptive optics and atmospheric compensation technology (highly classified until 1991) has provided astronomers unprecedented performance for their ground-based telescopes. Today, every new large ground-based telescope employs adaptive optics technology, thereby enabling exquisite resolution of celestial objects. More recently, the same technology has been applied to achieve unprecedented medical advances. Adaptive optics have produced the best images yet obtained of the human eye, and the techniques may eventually lead to the development of tailored contact lenses that can give humans "super-normal," or better than 20-20, vision. If DoD S&T funding continues to decline, transfer of DoD laser technologies will simply cease to occur.

Finding 5: The DoD should leverage HEL relevant research being supported by the DOE and other government agencies, and also by commercial industry and academia.

DOE is funding related HEL technologies such as Solid State Lasers and new beam diagnostics. The development of such technologies has potentially large payoffs if leveraged properly to DoD weapons applications. Conversely, DoD developments in HEL technologies may have significant potential for DOE missions, and DOE should take advantage of those developments. Also, advances in SSL, simultaneously being pursued by both DoD and DOE, could be coordinated more effectively. The DOE National Laboratories have opened the door to new lethality mechanisms that offer options for defeating targets with lower power lasers than previously thought. This should provide a rich set of opportunities for DoD-DOE collaboration.

Finding 6: It is increasingly difficult to attract and retain people with the critical skills needed for HEL technology development.

The deficiency in HEL S&T funding has also impaired the ability of the DoD laboratories to attract and retain people with the critical skills needed for HEL technology development. Many DoD agencies and laboratories no longer maintain an in-house technical expertise in key technical areas, which means the Government's ability to be a "smart buyer" has deteriorated to a low level. There are numerous examples where physicists, optical experts, laser device chemists and engineers, and large optics designers have been hired and, in some cases, trained at great expense, only to be lost to better-paying or more exciting opportunities in the commercial sector. While it is good that the US enjoys a thriving commercial sector, DoD should ensure that S&T funding permits those in the HEL field to enjoy attractive and rewarding careers in government and industry if we want the advantages of HEL weapons in the future. HEL demonstration programs under way today are based on the substantial investments of the mid- to late-1980s. The basic concepts in laser devices and beam control for today's programs came from approaches developed even earlier, in the 1970s. The ability to field more capable HEL weapon systems in the future depends on maintaining a base of people with the necessary skills.

Recommendations

The Panel made the following recommendations that address the findings. Three of the Panel's four recommendations — management structure, S&T funding, and industrial base—are interrelated, and must be executed together to have the desired results. The fourth recommendation supports stronger cooperation among the HEL research programs of the DoD, the DOE, and other government agencies to maximize opportunities for collaboration.

Recommendation 1: DoD should implement a new management structure for HEL technologies.

The findings indicate that HEL technology and weapons development suffer from a lack of S&T funding. However, it is not realistic to expect that new or rededicated funding alone will fully rectify existing problems. The existing management has not been able to resolve the fragmented, disjoint nature of HEL technology development.

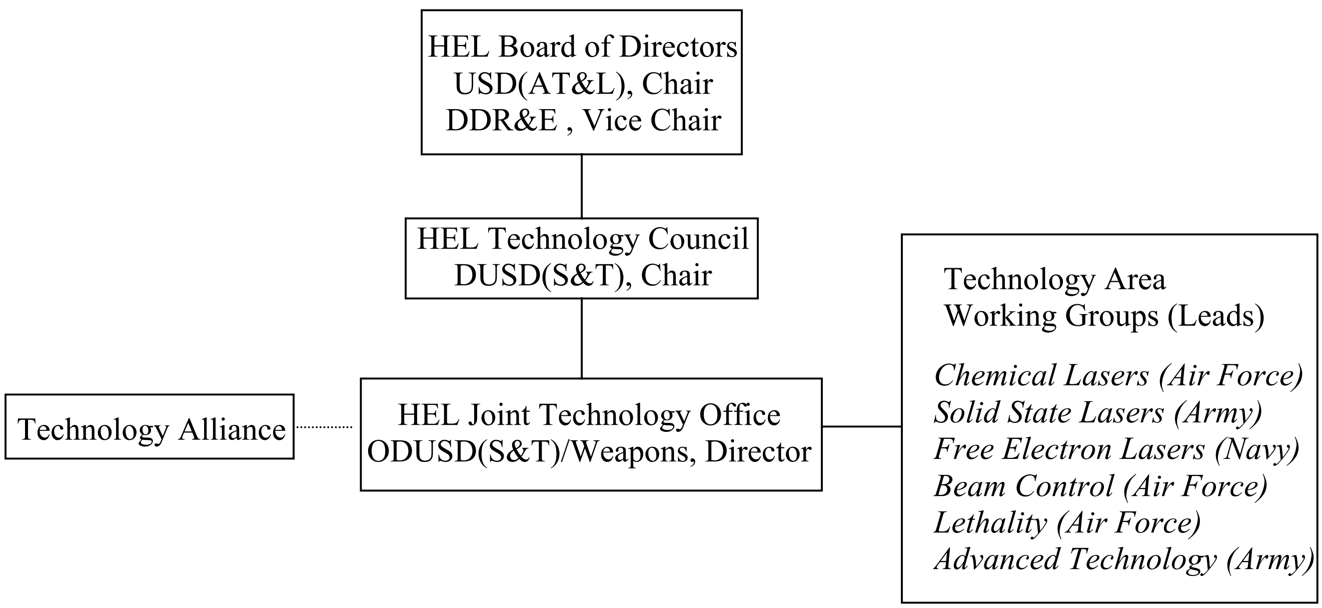

Figure 5. Recommended management structure for HEL technologies.

An outline of the management structure developed by the Panel is shown in Figure 5. It features a Joint Technology Office (JTO), tasked with the development and day-to-day management of a joint program for revitalizing HEL S&T. The JTO will also serve as a clearinghouse for new S&T initiatives proposed by DoD components. The JTO should have an SES-level Director, who reports to the DUSD(S&T), and a military support staff whose members will also serve as liaison officers for their respective Service. Technology Area Working Groups (TAWGs), composed of representatives from all DoD stakeholder organizations, will support the JTO in developing detailed technology roadmaps. The TAWGs are listed by technology area, with the initial Service leads as shown. The JTO will also maintain a Technology Alliance to foster information exchange and cooperative activities with other government organizations, universities, and industry.

Senior-level oversight would be accomplished through a Technology Council and a Board of Directors. The Technology Council, shown as chaired by the DUSD(S&T), would have a membership that includes the Senior S&T Executives from the Services, DARPA, BMDO and DTRA, and be responsible for reviewing and prioritizing the technology programs proposed by the JTO and making funding recommendations. The Board of Directors, shown as chaired by the USD(AT&L) with the DDR&E as Vice Chairman, would have a membership that includes the Service Acquisition Executives (SAEs), and the Directors of DARPA, BMDO and DTRA, and be responsible for reviewing and validating the S&T funding recommendations in the context of Department-wide HEL programs.

Recommendation 2: DoD should increase funding allocated to HEL S&T to achieve a better balance between large demonstration programs and enabling S&T programs.

From the panel's point of view, the best alternative for adequately funding HEL S&T is simply to increase the S&T "top line." This would have the benefit of retaining high-priority national programs while correcting some of the funding deficiencies associated with technology base and applied technology demonstration programs. Given the precipitous declines in S&T funding over the last decade, the Panel favored the investment of new resources. Such an increase would, however, have to compete with other DoD needs.

While the Panel unanimously expressed a strong need to invest in long-term technologies, there was an equally strong sentiment that the investment should not be S&T in the abstract. Technology roadmaps should show a clear pathway to take these technologies to concept implementation, using clearly defined metrics and exit criteria that specify either passage or failure at specific milestones. Examples of concrete long-term technologies include closed-cycle chemical laser devices, solid-state laser devices, advanced beam control and laser beam quality improvement technologies, and lethality assessments. (More examples will be given in the next section.)

Recommendation 3: DoD should stimulate the HEL industry supplier base with a few focused investments.

The Panel strongly supports new investments in a relatively modest, near-term system application of HEL technology. This can demonstrate the utility of lasers as a viable weapon technology, while at the same time stimulating the industrial supplier base. The focus for such investments should be to fill the current gap between the very low-power laser systems and the very high-power applications such as ABL. While requirements for intermediate power laser systems are just now emerging, such weapons have attractive features for short-range, lethal and non-lethal engagements. These applications (tens to several hundred kilowatts) would also serve as an opportunity for evolutionary improvements to chemical lasers and represent an achievable goal for revolutionary developments in solid state lasers. For example, the demonstration of a Sealed Exhaust System (SES) chemical laser operating at tens of kilowatts would serve to focus technology development on one of the significant limitations of current chemical laser systems, namely, the presence of effluents. Similarly, an electrically rechargeable version of this technology would solve another issue in chemical lasers, namely, the finite magazine size.

While demonstration programs are important, basic technologies in each of the HEL areas are still at issue. The Panel recommends that efforts be prioritized in each of the technology areas and that focused efforts be funded to revitalize the industrial base. Toward that end, the Panel considered the top three technology thrusts in each area as candidates for funding. The following lists describe these high-level roadmaps.

Solid State Lasers:

- Develop and demonstrate coherently phased fiber arrays
- Scale-up Heat Capacity Laser (HCL) to 100's kw
- Develop low cost diodes

Chemical Lasers:

- Improve high priority laser devices (Chemical Oxygen-Iodine Laser (COIL) for ABL, Hydrogen-Fluoride (HF) for SBL, Deuterium-Fluoride (DF) for Mobile THEL), including Modeling and Simulations
- Produce tactical-friendly closed cycle COIL, DF. Evaluate Airborne Tactical Laser (ATL) device, engineer Electric-COIL, examine DF
- Evaluate electrically pumped, novel hybrid approaches (Diode pumped oxygen iodine laser, electrically pumped oxygen iodine laser)

Free Electron Lasers:

- Develop High Average Current Injectors
- Develop High Power Resonators/Undulator
- Develop High Average Current Electron Beam Transport

Beam control:

- Develop components (many different components, including illuminators, sensors, mirrors, coatings, etc.)
- Continue development in optical component and coating measuring technologies
- Continue developmental and integrated testing (e.g., at Starfire Optical Range and North Oscura Peak)

Lethality:

- Characterize advantages of pulsed vs. Continuous Wave (CW) effects
- Increase modeling and simulation of lethality mechanisms
- Evaluate Electro-Optic (EO) sensor vulnerability and battle damage assessment

Advanced Technology:

- Develop technology to support full power Relay Mirrors (studies, concepts, data collection)
- Examine femto-second laser effects and devices
- Research new SSL materials (different concepts for radiation-cooling, various wavelengths, efficiency, high-temperature operation, heat capacity)

In reviewing the US HEL technology efforts, the Panel found that total HEL funding would have to increase substantially to adequately fund even the top three priorities in each technology area. For the full recommended U.S. HEL program in these technologies, the funding would have to increase further. Again, the Panel emphasized that projects as large as the SBL Integrated Flight Experiment (IFX) should not be funded out of S&T accounts. Instead, such projects should use Large Scale Demonstration, or Prototype Demonstration and Risk Reduction (PDRR) funding out of 6.4 accounts. Education and training in HEL technologies can take the form of dedicated university programs, scholarship funds, grants for fundamental research, and Multi-disciplinary University Research Initiatives (MURI). With these caveats, the total HEL-related S&T funding for the recommended program to develop weapons for the US arsenal is significantly more than the current investment of $227M as shown in Table 2.

Table 2. Current funding in principal HEL technology areas (S&T only).

Technology Area	FY00 Funding ($M per year)
Solid State Lasers	26
Chemical Lasers	3
Free Electron Lasers	10
Beam Control	26
Lethality	4
Advanced Technology	10
Integrated Demonstrations S&T	148
Total Technology	227

The Panel recommends that DUSD(S&T) submit an input to the FY2002 POM for enhanced HEL S&T funding. While recognizing the importance of system demonstration projects, the Panel also strongly recommends that a reprogramming be considered for FY2000 and FY 2001 to meet the immediate need for HEL S&T.

Recommendation 4: The DoD should investigate the potential for cooperative programs with the DOE and other government agencies, industry, and academia.

The DoD should take advantage of the significant investments and capabilities resident in DOE laboratories and elsewhere. The panel strongly endorses DoD initiatives to pursue collaborative arrangements and to leverage their research programs through mutually beneficial activities. A model for such a cooperative program is the continuing DoD/DOE Joint Munitions Program, which features a 50/50 cost sharing arrangement and joint prioritization of technologies.

Conclusions

Together, the recommendations comprise a restructured perspective in developing HEL weapons. Developing revolutionary capabilities in HEL weapons requires a coordinated and focused investment strategy under a new management structure, featuring a Joint Technology Office with senior-level oversight provided by a Technology Council and Board of Directors. Any new investment strategy must also recognize the need to achieve a better balance between large demonstration projects and enabling S&T projects. Currently, about 70% of the total HEL S&T funding is dedicated to large-scale system demonstrations. In the future, a better balance could be achieved by transitioning large demonstration projects to non-S&T accounts sooner than has been done in the past. For the present, either new S&T funding must be identified, or at a minimum, the present imbalance between integrated demonstrations and S&T should be corrected through a reallocation of total S&T funding. The Panel recommends that the Office of the DUSD(S&T) submit an input to the FY2002 Program Objective Memorandum (POM) for enhanced HEL S&T funding. While recognizing the importance of system demonstration projects, the Panel also strongly recommends that a reprogramming be considered for FY2000 and FY 2001 to meet the immediate needs for HEL S&T.

Appendix A: Panel Members

The High Energy Laser Executive Review Panel (HELERP) was convened by the Deputy Under Secretary of Defense (Science and Technology) with participants from OSD, all three Military Departments, and the principal Defense Agencies that have a potential interest in High Energy Laser technology.

Name	**Organization**
Dr. Delores Etter, Chair	DUSD(S&T
Dr. George Ullrich	ODUSD(S&T)/WS
Dr. Jim Riker	ODUSD(S&T)/WS
Dr. Jim Mulroy	OD,S&TS/MW
Dr. Rick Wallace	ODUSD(AS&C)
Dr. Tom Meyer	DARPA
Dr. Bruce Pierce	BMDO
Dr. Darrell Collier	Army
Dr. Larry Stotts	Army
Dr. Eli Zimet	Navy
Dr. Barry Hogge	Air Force
Mr. Ed Duff	Air Force

The Panel also made use of several subject area experts for their individual technical inputs. In particular, the significant technical contributions of Dr. Mike Perry (Lawrence Livermore National Laboratory) and Dr. Bob Cooper (Consultant) are hereby acknowledged.

Appendix B: List of Meetings with Associated Themes

Meeting Date	Theme	Briefers
15 October 1999	Kickoff, Introduction	Services, Boeing, TRW
29 October 1999	Major Laser Programs	THEL, ABL, SBL
19 November 1999	Laser Technology Programs	FEL, SSL, GBL/ABL technology
9 December 1999	Industry Perspective	Raytheon, Boeing, Lockheed, SAIC
7 January 2000	Industry Perspective	Xinetics, tOSC, Northrop, ABL Program Office
25-27 January 2000	Facility Tours California	Boeing, Raytheon, TRW, LLNL
15-17 February 2000	Facility Tours New Mexico	HELSTF, THEL, ABL/NOP, AFRL/SOR, AFRL

List of Acronyms

ABL	- Air Borne Laser
ACTD	- Advanced Concept Technology Demonstrator
AFRL	- Air Force Research Laboratory
AOA	- Adaptive Optics Associates
ARL	- Army Research Laboratory
ATL	- Airborne Tactical Laser
ATP	- Acquisition, Tracking and Pointing
BC	- Beam Control
BMDO	- Ballistic Missile Defense Organization
BOD	- Board of Directors
CL	- Chemical Laser
COIL	- Chemical Oxygen Iodine Laser
CW	- Continuous Wave
DARPA	- Defense Advanced Research Projects Agency
DDRE	- Director, Defense Research and Engineering
DF	- Deuterium Fluoride
DoD	- Department Of Defense
DOE	- Department Of Energy
D,S&TS	- Director, Strategic and Tactical Systems
DTRA	- Defense Threat Reduction Agency
DUSD(AS&C)	- Deputy Under Secretary of Defense for Advanced Systems and Concepts
DUSD(S&T)	- Deputy Under Secretary of Defense for Science and Technology
EO	- Electro-Optic
FEL	- Free Electron Laser
FY	- Fiscal Year
GBL	- Ground Based Laser
HCL	- Heat Capacity Laser
HEL	- High Energy Laser
HELERP	- High Energy Laser Executive Review Panel
HELSTF	- High Energy Laser System Test Facility
HF	- Hydrogen Fluoride
ICBM	- Inter-Continental Ballistic Missile
IFX	- Integrated Flight Experiment
LANL	- Los Alamos National Laboratory
LLNL	- Lawrence Livermore National Laboratory
LMP	- Laser Master Plan
MOU	- Memorandum of Understanding
MURI	- Multi-disciplinary University Research Initiative
NASA	- National Aeronautics and Space Administration
NOP	- North Oscura Peak (on White Sands Missile Range)
NRL	- Naval Research Laboratory
NRO	- National Reconnaissance Office
OCLI	- Optical Coatings Laboratory Incorporated

ODDRE	- Office of the Director, Defense Research and Engineering
ODUSD(S&T)	- Office of the Deputy Under Secretary of Defense for Science and Technology
OSD	- Office of the Secretary of Defense
PDRR	- Prototype Development and Risk Reduction
POM	- Program Objective Memorandum
RDT&E	- Research, Development, Test and Engineering
RM	- Relay Mirror
RSC	- Rockwell Science Center
SAE	- Service Acquisition Executives
SBL	- Space Based Laser
SES	- Sealed Exhaust System
SOR	- Starfire Optical Range
SMDC	- Space and Missiles Defense Center
SPO	- System Program Office
SSL	- Solid State Laser
S&T	- Science and Technology
SWIR	- Short-Wavelength Infra-Red
TBM	- Tactical Ballistic Missile
THEL	- Tactical High Energy Laser
TWG	- Technology Working Group
USAF	- United States Air Force
USD(AT&L)	- Under Secretary of Defense for Acquisition, Technology and Logistics
WG	- Working Group
WSMR	- White Sands Missile Range