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WEAPONS
A Report on the Industry

Industry Study 5240-11

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WEAPONS

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Air Force Research Laboratory, Kirtland AFB, Albuquerque, NM
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WEAPONS

"It is by devising new weapons, and above all by scientific leadership, that we shall best cope with the enemy's superior strength"

Winston Churchill
3 September 1940 (1)

ABSTRACT

The weapons industry provides critical support directly to the military element and indirectly to other (e.g., diplomatic, informational, and economic) elements of national power. The industry, with products ranging from nuclear weapons to non-lethal arms, is frenetic—with large and small, expanding and contracting, robustly funded and withering segments. Given this breadth, we chose to focus on three areas: small arms, non-lethal technologies, and energetics. We chose them because transformation has not taken hold across these areas as they have fallen beyond mainstream focus. Energetics remains under the purview of government laboratories, non-lethal technologies are interesting, but nascent, and the soldier and his rifle are an icon of legacy systems. To preserve comparative advantage, we recommend a strategic review of these segments of the weapons industry. This review should determine if these segments are poised to deliver needed capabilities and if over-focus on high-end precision denigrates the role of small arms, non-lethal technologies, and energetics in national power.

INTRODUCTION

The United States' technological superiority, as evidenced by its advanced, high-end weapons systems, was key to its Cold War victory. Further, these weapons, with their far-reaching and devastating effects, have solidified the unique power and formidable strength of our armed forces. Whereas the precision guided or "smart" weapons of the United States are unparalleled, this is not so for those placed into the hands of its infantrymen. It is vital to consider not only missiles but also weapons at the "soldier end" of the continuum. For, at the frontline of America's defenses, at the tip of its spear, stands the soldier armed with his rifle. Today, it is the infantryman, who scours the hills of Afghanistan and patrols the streets of Baghdad. The geopolitical situation at present (and in the foreseeable future) highlights the soldier as the definitive expression of national military power and an integral agent of the National Security Strategy. As the US embraces the concept of network centric warfare, it must consider a crucial node—the soldier. He is a critical element in an ever increasing, interdependent and integrated system. Thus, we must leverage the power, energy, delivery, and effects of our approaches to precision guided munitions into the transformation of small arms.

History, the nation, and the weapons industry have come full circle. With the defeat of its strategic adversary, the United States left the Nuclear Age and returned to the Age of the Soldier. Increasing intra-state conflict and transnational terrorism have inextricably drawn the nation back into the "savage little wars of peace" that marked most of its history. Facing a future of soldier-intensive peacekeeping and humanitarian operations, the nation has recognized its dependence on the foot soldier to protect its national interests at home and abroad. Recognized as *Time* magazine's 2003 "Person of the Year," (Gibbs, 32) the soldier is the weapon of choice in a future described by Vice Admiral Cebrowski (Retired) as "the age of the small, the fast, the many" (Cebrowski, 3). In conjunction with this change in mission is an increasing political sensitivity to deaths, injuries, and collateral damage which is driving the nation to seek more non-lethal and precision weaponry.

The weapons industry must revisit its historical roots. The combined effects of diminishing domestic markets and increasing costs are atrophying the industry's Cold War muscle. The industry is extremely fragile, precariously balanced between aging existing small arms weapons and immaturity of emerging non-lethal weapons. Ironically, the nation that gained its independence behind the Minutemen armed with British "Brown Bess" and French Charleville muskets and fought its civil war with British Enfield and Austrian rifles, once again finds itself increasingly reliant on foreign sources for small arms.

Whereas past studies of the weapons industry have focused on "high end" precision weaponry, the foci for 2004 were energetics, small arms, and non-lethal weapons. The timing of this study is propitious. In the perennial "guns vs. butter" debate of budgetary priorities, we see the war on terror and tomorrow's nonlinear battlefields voicing strong arguments for strategic investment in soldier-level capabilities. The geopolitical realities of terrorism, deployments to the Balkans, Afghanistan, and Iraq, and nascent transformational efforts demanded this focus. As with those at the high end, soldier-end weapons must be sourced from a robust, reliable, and adequately resourced developmental pipeline, capable of leveraging scientific advancements in an efficient and expeditious manner. This report describes that pipeline and its ability to provide the 21st Century soldier the tools to ply his trade, to defend his country, his compatriots, his allies and his life. This 2004 study was conducted via three teams corresponding to the segments of the industry assessed. This report draws from the combined experiences of the participants, classroom seminars, literature reviews, case studies, domestic site visits, and international field studies to assess the status and health of the weapons industry and its role in national security.

In addition to summarizing the industry segments studied, separate essays are included that discuss in greater depth, directed-energy non-lethal weapons and energetic munitions. The points on small arms form the primary threads of discussion in the body of this paper and will not be highlighted in essay form. From these waypoints, the paper charts the course for the future of weapons development and its anticipated effects on US national security and force transformation. The report concludes by setting forth recommendations for improving the weapons industry and the developmental process.

DEFINING THE WEAPONS INDUSTRY

The weapons industry creates a complex system of weapons composed of technology, lethality, and probability of employment (see Figure 1), executed by a diverse mixture of research laboratories, government operated plants, and commercial corporations. The industry includes large, familiar platform manufactures and system integrators such as Lockheed Martin and Boeing delivering systems across the spectrum. Smaller, independent sub-contractors and government laboratories provide the basic building blocks of weapons or deliver niche systems. In between is a large group of system and weapons suppliers supporting legacy segments of the weapons industry.

The large weapons suppliers often are referred to as the megalithic "military industrial complex" (Eisenhower, 2), but they pale in size next to well-known large global corporations. For example, Wal-Mart and Ford had 2003 revenues of $259B and $164B compared with $31.8B for Lockheed Martin and $50.5B for Boeing (Forbes, 1). Even these numbers are deceiving because Lockheed Martin and Boeing derive a significant amount of their revenue from their commercial interests - $11.4B for Lockheed Martin and $23.2B for Boeing.

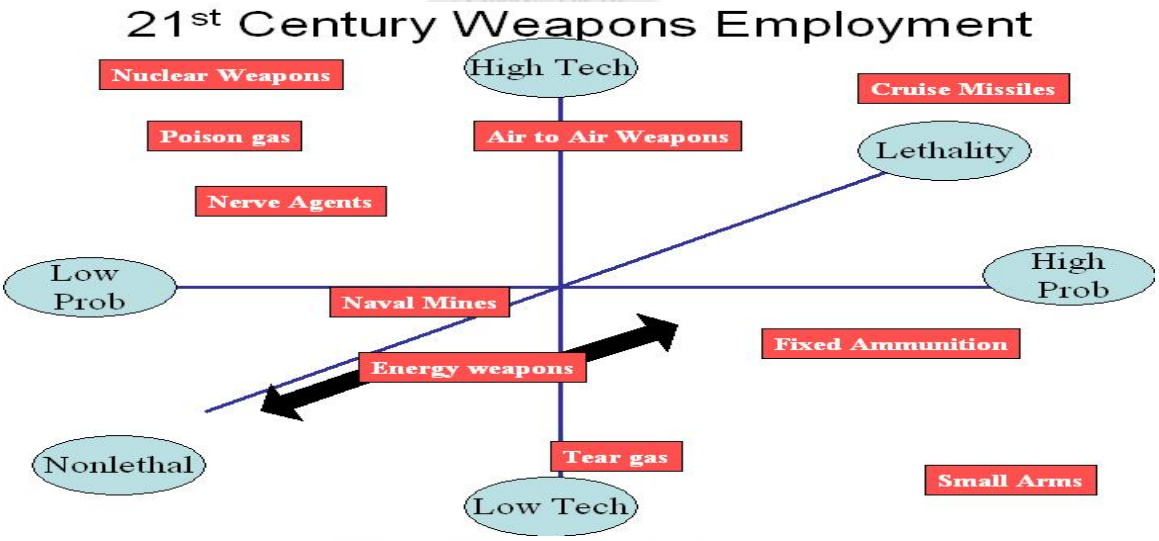

Figure 1 - Weapons Spectrum

For small arms, energetics, and non-lethal weapons, the industrial base is limited to mainly small companies and government laboratories. For each of these industry segments there is a different supply chain. The "official" small arms industrial base identified by Congress (United States, 1) consists of three companies, Colt Manufacturing, Fabrique National Manufacturing Incorporated (FNMI), and SACO Incorporated (a subsidiary of General Dynamics). The "unofficial" small arms industrial base consists of companies such as Beretta, who supplies mostly pistols and CAPCO, who provides replacement and modification parts.

The industrial base for non-lethal weapons is emerging and amorphous. Given these conditions, it is unclear what companies will comprises the industrial base for non-lethal weaponry. Therefore, financial performance in the non-lethal weapons sub-industry is not discernable.

The energetics industrial base is made up of several specialized manufacturers and government labs. They include Department of Energy facilities, Lawrence Livermore being the most prominent, and Department of Defense facilities, such as the Air Force Research Laboratories and Indian Head Naval Weapons Station. The amount of funding expended by these entities is difficult to quantify for two reasons. First, it is difficult to decide on the inclusion of the cost of basic energetics research into the total cost for weapons systems, (e.g. Tomahawk) and secondly, energetics research conducted independently of weapon systems (e.g. National Ignition Facility at Lawrence Livermore) hides other costs. Industrial involvement in weapons-related energetics has been limited to small-scale production of components or the provision of raw materials, such as Ammonium Perchlorate. Limited scale production of energetic weapons, such as thermobaric compounds used in Operation ENDURING FREEDOM, was produced from conception to execution by the government "in-house." As a rough order of magnitude, energetics research, development, test, and engineering, totaled some $400 to $500M in 2003 independent of special projects. In terms of value produced, both for commercial and military applications, the figure approaches $1B per year.

CURRENT CONDITIONS

The current condition of the weapons industry will be discussed vis-à-vis three distinct but interrelated areas: the weapons industry market, the domestic industrial base and current US policies governing manufacture and export.

Market. The post cold war geopolitical landscape has seen a reduction in the worldwide demand for weapons, both in the small arms and in the high tech Precision Guided Munitions (PGM) arenas. This reduced defense demand has driven weapons manufacturers toward commercial markets, consolidation, or completely out of the industry. The only growth market in firearms is in the Law Enforcement and Security realm as a result of increased security requirements. With the contraction of domestic defense markets, remaining weapons manufacturers are aggressively attempting to leverage the global weapons market to replace domestic demand. In addition, with domestic demand low, international mergers are becoming increasingly popular as a means for suppliers to survive. Both European arms manufacturers and similar US firms are seeking consolidation to capitalize on access to multiple domestic and military markets. Trans-national consolidations may bring some risks for the US. Namely, the export of technology, licensing, and production capabilities could lead to US dependency on foreign government policies regarding advanced small arms technology. Worse yet, consolidations and mergers may result in the evaporation of an indigenous US small arms production capability, resulting in dependence on one or more foreign governments for critical small arms and small arms components. Foreign-owned manufacturers could have governments with priorities that may not always coincide with US priorities. This poses a threat to US national security, as small arms play a significant role in current and future asymmetric scenarios.

Industrial Base. For the purposes of this paper, the industrial base is divided into two distinct categories, legacy systems with contemporary small arms, and highly

technical emergent or transformational systems. Overall, the current state of the weapons industrial base is characterized by reduced demand and extremely slim profit margins. This lack of profit potential, coupled with the extensive initial capital investment required, limits entry into the market and, arguably, contributes to atrophied innovation and limited research and development. Most weapons industries follow demand; profit and response to shareholders is and should be the primary driver of weapons manufacturers. However, there remain isolated, state run enterprises in both Asia and other emerging nations. As globalization continues, we expect these isolated industries to be subsumed in larger free market enterprises.

Weapons production of the quality demanded by the US government entails significant reliability standards. Thus, it is labor intensive and requires extensive automation in terms of computer controlled and performance diagnostic equipment. The cost of labor and production equipment inhibits capital investment and prevents manufacturers from maintaining excess capacity that could be used to meet surge requirements. Therefore, these conditions present significant barriers to entry and exit from these markets.

The move toward the consolidation of small arms manufacturers into multinational companies could have a negative effect on US domestic small arms production capability. If these multinational small arms manufacturers decide to take small arms production offshore, an evaporation of US manufacturing capability could result, with a lengthy start-up should the US need a stand-alone capability.

US Government Policy. The US government is currently leveraging foreign owned suppliers for small arms capability by requiring on shore production of weapons. The trend in US procurement for small arms is to continue on a path that seeks solutions from available foreign and commercial sources. As an example, FNMI, owned by Fabrique National of Belgium, manufactures the M-249 machine gun, which it produces in Columbia, SC. The 1997 Defense Authorization Act allows the Secretary of Defense to take actions to protect the US small arms industrial base (United States, 1). Specifically, the Secretary of Defense "may require that any procurement of property or services…for the Department of Defense be made only from a firm in the small arms production industrial base." This arrangement works well if the commercial and foreign sources operate in a healthy market with incentives such as support for investment, research and development, and stable contracting.

Yearly appropriations, vice a long-term congressional funding strategy, make long term planning and program decision difficult and thus serve as a barrier to entry into the weapons market. A lack of budgetary discipline, such as the use of supplementals, significantly contributes to turbulence and uncertainty amongst suppliers and potential entrants. Fewer competitors results in reduced competition, a lack of robust research and development investment, and stagnating innovation.

The US government assumes liability and litigation responsibility for defense weapons manufacturers. However, there is a lack of protection from frivolous litigation associated with commercial production. Threats to the commercial portion of the industry indirectly threaten defense production.

Weapons acquisition continues to have a service and protectionist approach that limits true "joint" and coalition weapon integration. The DoD definition and

classification of lethal versus non-lethal weapons, along with international treaties and conventions limits development of a truly transformational small arm. Government restrictions on arms technology transfer contribute to the increasing technology and capability gap between the US and allies. Additionally, improvements made to weapons manufactured in the US are subject to rigorous export controls. These policies result in significant barriers and disincentives to both small arms and non-lethal weapon development.

CHALLENGES

Perhaps the greatest challenge for the small arms weapons industry is visibility. This sector is tiny relative to the overall US weapons industry. Small arms purchases are less then 0.3% of the overall weapons procurement budget in DoD as shown in Figure 2. Understandably, DoD has invested billions, if not trillions of dollars over the last few decades developing high tech precision weapons and weapon systems. In a world where a few million dollars is a rounding error in a trillion dollar budget, the costs associated with small arms can easily go unnoticed and therefore, unfunded.

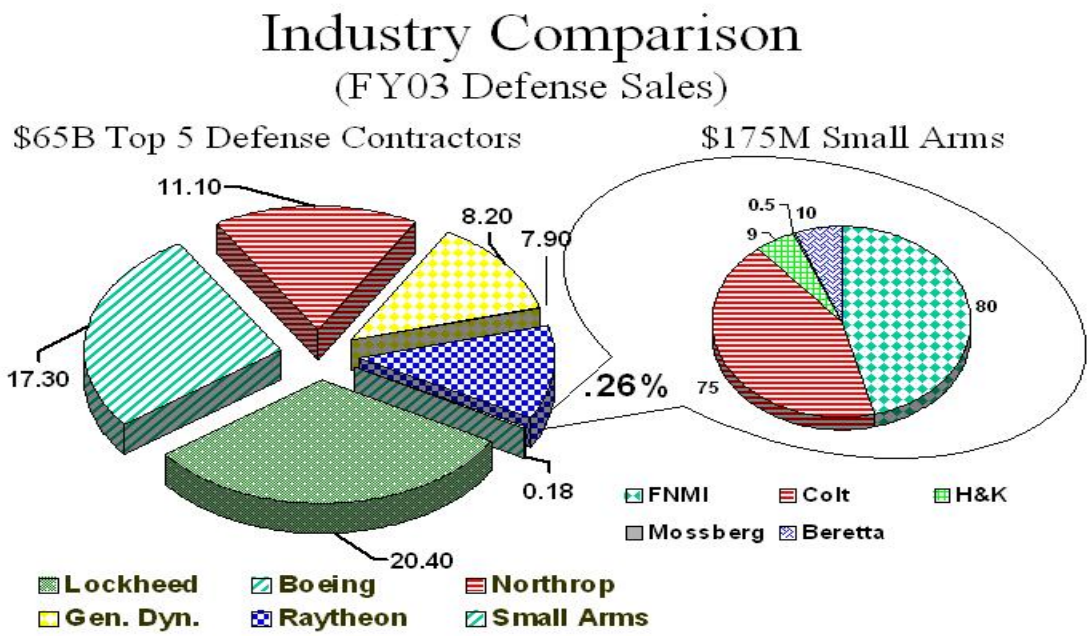

Figure 2 - Economic Comparison (Forbes, 1 and Site Visits)

US Defense leadership is facing a decision on the risks associated with the weapon industry's inability to surge rapidly and whether to take action to purchase industry over-capacity recognizing that, for the most part, it will remain idle for long periods of time. The weapons industry must be highly efficient to remain competitive. Adoption of Six-Sigma, lean manufacturing processes, just-in-time logistics and other efficiency programs has resulted in an industry with capacity that essentially matches current demand. Although this results in cost savings to the customer, it limits the

industry's ability to surge rapidly to meet an immediate national need. There is a general consensus among industry officials that it would take approximately six to eight months to increase production by 50 percent in any major weapons line. It would take a year to increase production by companies with weapons manufacturing capability that have never previously produced the particular weapon requiring surge production. Industry officials also expressed great reluctance to surge production for only a year or two, much preferring to build steadily over longer periods of time. Short-term surges increase friction and turbulence within their companies. Quick money cannot buy a rapid surge in production.

US Defense leadership should decide whether to accept the static state of small arms technology or invest US tax dollars to invent new, transformational small arms. For example, should the US buy the XM-8 (HK-USA, 1) at around $2B, or invest in small arms R&D to develop a transformational weapon? Today's cruise missiles can launch from the deck of a ship, fly more then 100 miles and then destroy a target by entering the second story window of a building. This is certainly a capability relevant during the cold war world as well as in today's geo-political context. What DoD did not invest money in was development of capabilities for the individual soldier's weapon.

Small arms manufacturing is not the industry of choice for those seeking fortune. Large weapons manufacturers, like Boeing, Raytheon, BAE, and Northrop-Grumman have avoided investing in small arms manufacturing. The risks are too high and the profit margins are too slim. Most small arms manufacturers have established separate legal entities to protect commercial manufacturing and military manufacturing from each other because litigation has cost the industry millions and millions of dollars. Despite these efforts to provide legal barriers, most manufacturers harbor little doubt that the collapse on one side will probably lead to the collapse of the other. The cumulative effect is small arms manufacturers lack significant capital--capital that could be used for research and development. Today's infantry rifle and side arm are using essentially the same technologies used for over 50 years. Even the most modern combat rifles offered by industry (such as the XM-8 or F-2000) (F-2000, World Guns, 1) are variations on a theme. They are iterative changes in technology, not yet evolutionary, let alone transformational. The resources necessary to develop new, transformational technologies are not resident in the industrial base. Any significant innovation in the capabilities of the small arms weaponry of the individual soldier will come from government investment.

The small arms industry is faced with an aging workforce. The average age of an employee in most of the US based manufacturing plants exceeds 45 years. The industry must find and train a younger workforce today, prior to the retirement of senior members tomorrow. Industry has moved away from 'touch' labor to automated processes resulting in significant productivity increases. There appears to be an industry-wide policy of giving retention preference to those with the greatest seniority. Retention of these senior workers possessing touch labor skills, coupled with job losses from automation results in a loss of younger members of the workforce. It is these younger members who were more likely to the possess new skills associated with an automated shop.

US military and legislative leadership should re-examine legislation regarding litigation and the small arms industry. Additionally, they ought to consider foreign market practices that disadvantage domestic manufacturers. Or, leaders must consciously

decide to forego the domestic base and be willing to accept dependence on foreign owned/operated small arms production.

Forces existing in both commercial and government markets impact small arms manufacturers. Currently, market forces threatening the US commercial industry endanger domestic military production. Specifically: litigation against firearm manufacturers over criminal use of their products; reductions in the sporting firearm population; closure of overseas markets by foreign legislation and regulation; and finally, subsequent increased competition from overseas commercial manufacturers looking for new markets after closure of their national markets, all combine to seriously threaten the domestic industry.

WEAPONS INDUSTRY OUTLOOK

In the near term, we predict the weapons industry will remain healthy. DoD Total Obligation Authority is $380B in Fiscal Year (FY) 2004 and is programmed to rise to over $400B in FY05. Beyond FY05, defense spending may flatten or decline. Influencing this trend are growing federal budget deficits and potential changes in force structure and organization. Outlooks for the small arms, energetics and non-lethal segments of the weapons industry are presented in the table below. Subsequently, a discussion of market, financial, and technology trends for these industry components is provided.

Outlook for Small Arms, Energetics, and Non-lethal Segments of the Weapons Industry (Through 2004)

SMALL ARMS	ENERGETICS	NON-LETHAL
Domestic market will remain stagnant ↔	Developing technology with a _definite military market ↑	Maturing technology searching for a military market ↑
Declining capital investment across the industry ↓	Government R&D investment will develop the technology ↑	Government R&D and industry IR&D investment will mature the technology ↑
Limited innovation and revolutionary change due to lack of investment ↓	High innovation driven by funding and technology maturity ↑	High innovation driven by funding and technology maturity ↑
Uncertain surge capability ↔	Limited surge capability ↔	Increased surge capability ↑

The arrows refer to static ↔, dynamic ↑ and decreasing ↓

Figure 3 - Weapons Outlook

Market. The domestic small arms market is expected to remain stagnant. This market subdivides into three groups with their own distinct prospects. The commercial sector, which caters to the sportsman, appears to be declining because of loss of hunting land and diminishing interest. However, law enforcement and security requirements will continue to grow. With greater emphasis on smaller but more lethal military forces, new generation small arms purchases will not be as voluminous as legacy small arms. Therefore, the overall market will not be driven by DoD's demands, but by other

organizations, to include the Department of Homeland Security, as well as state and local entities. However, before procurement begins, the issues of liability, long-term human effects, and operational employment must be resolved.

As future technologies mature, energetic (in particular the electronics portion) systems will continue to develop. As with non-lethal weapons, energetics has yet to earn a definitive place in our National Defense Strategy. Once that place is secured, they can be integrated into the military's capabilities.

The future surge capability of domestic and international small arms manufacturers will be limited because the industry will continue to match capacity to demand. The graying workforce will also limit future surge capability. Lacking investment for re-capitalization, much of the machine tooling will age. To survive, manufacturers will continue to seek greater efficiencies by shedding workers and eliminating inefficient production processes. The ability of suppliers to surge to support the primes also may be a limiting factor. To meet surge requirements in the future, the US is likely to increase small arms purchases from foreign-held companies operating in the US or in their overseas facilities. Manufacturing of energetic and non-lethal weapons is nascent and much of the production seen to date has been of weapons prototypes. Surge capability is unclear because of uncertainty in the supplier base.

Financial. Declining investment capital and a decline in military contracts keep small arms production lines at best "cool" and more likely will lead to closure. With few new military programs and little interest from investors, the weakest of the few remaining domestic and international small arms manufactures, together with their vendors, may fail. This scenario increases US dependence on foreign companies for systems and spare parts. The risk to the US is that the governments where these companies reside could withhold capital or ban sales of small arms should international policies differ. Energetics and non-lethal weapons, on the other hand, are not subject to market influences as they receive nearly all of their funding from government sources. Such funding will continue enabling the development of these technologies.

Litigation will continue to cast a pall over the small arms industry. There is no indication that Congress will pass legislation to protect the industry from litigation. This uncertain legal environment inhibits the industry's ability to attract investment. To date, litigation has provided no precedents similar to those found in "asbestos cases." As more lawsuits come forward and new case law is established, further restrictions could impact the industry. For example, the threat of possible litigation resulting from a major plant accident (e.g. the Ammonium Perchlorate explosion in Henderson, Nevada) (Exponent-Multimedia, 1) presents a significant disincentive to investment. Non-lethal weapons also may face potential litigation, especially in the law enforcement area. Human effects research is still embryonic with little understanding of potential long-term consequences. Therefore, industry views further investment in non-lethal technology as high risk.

Technology. The small arms industry lacks the funds and markets needed to aggressively invest their own corporate research and development money for innovation. The most we can expect from industry is incremental upgrades to legacy systems. With legacy systems coming to the end of their useful life, the new programs designed to replace them, although potentially more lethal than existing platforms, are not

transformational. Industry's efforts likely will focus on improving processes to increase productivity and drive down costs. Future revolutionary or transformational change in small arms will come about only through government-funded research and development programs. The picture is different for the other two industry segments, in that technology and innovation will drive energetic and non-lethal weapons systems. Energetics technology is fostered by government sponsorship and non-lethal weapons are less constrained by litigation and are by definition burgeoning technology.

GOVERNMENT: GOALS AND ROLE

The relationship of the government to the weapons industry, and the resulting policy, procurement, and strategy reflect discrete periods of American history. In the era before World War II, the defense industrial and technology base was almost exclusively the province of army munitions plants and naval shipyards. The absence of an integrating agency – now embodied in the Department of Defense – combined with the small size of the military, limited opportunities for large scale, long duration, and therefore profitable, contracts to supply military technologies. The non-defense industry produced small arms and ammunition for domestic consumption and there were occasional contracts for fixed quantities of munitions (e.g. Winchester repeating rifles).

World War II changed for all time the relationship between the military departments, industry and Congress. The large-scale mobilization and conversion of industry to meet the requirements of wartime production provided the impetus not only for economies of scale, but for innovation, experimentation, and ultimately revolutionary developments, culminating in the fielding of nuclear weapons. In the wake of World War II, the United States rapidly converted industry back to domestic production, but began to witness a metamorphosis in warfare. Warfare would employ planes, rockets, and bombs versus soldiers, rifles, and bayonets. Governmental policy encouraged this transformation with funding and structural changes, to include the creation of a separate air force and the investment of hundreds of millions of dollars on aircraft weapon systems. At the same time, soldier systems relied on incremental improvements to firearms essentially developed in the 18th century. This investment strategy to devote large capital outlays for new technology combined with fractional investment in small arms and re-capitalization characterized defense policy until the 1980s.

The defense procurements that began in the late 1980s and continued virtually unabated throughout the 1990s delivered a plethora of new weapon systems, ranging from *Ticonderoga* class naval combatants to the B-2 stealth bomber. However, at the soldier level, the basic 5.56 rifle in various configurations continued to equip the 21st century ground war-fighter. In a broad sense, the policy and practice guiding weapon procurement was, and remains, threefold: first, to use long-range precision as a means of global engagement to reduce ground force deployments and thus limit subsequent causalities; secondly, to gain comparative advantage from technology and to maintain a world-leading defense industrial and technology base; and third to maintain legacy systems for ground combat operations with incremental improvements. By and large, this policy has been effective in creating a military capability second to none. However, in the mixture between government laboratories and production plants versus the

commercial sector, funding and profit have become the drivers versus innovation and the creation of effects-based operations.

The net effect of government policies since the end of World War II has been the creation of two tiers in both the weapons industry and in military forces. At the "high" end are robustly funded programs and production lines supporting precision engagement, aircraft systems, surface combatants, and information systems. At the "low" end are legacy soldier systems and the industries producing their products. A gray zone occupying the middle ground spins off research products virtually independent of combatant requirements, including non-lethal and energetic devices. The impact of government policies, therefore, is one of accidental capabilities, hammer-forged into operational concepts, and unintended comparative advantage. Furthermore, while we have moved ahead, this array of technology and capabilities has induced a significant and widening gap between the military capabilities of the United States and our allies.

To address the issues identified in the previous sections, namely the continuance of legacy soldier systems, the infatuation with high technology, and reality of profits for industrial viability, several policy pathways are possible. Given unlimited resources and pressing motivation, anything is possible. However, the reality is one of constraints in terms of budget, capacity, and visibility, especially in the small arms segment of this industry. Therefore, in broad terms, our policy goals are as follows:

- To create parity in capability and comparative advantage for all weapon systems,
- To procure weapon systems to achieve the broadest possible range of effects across the spectrum of conflict,
- To maximize the return on investment for public and private concerns engaged in the weapons industry, and
- To fully exploit the benefits of integrating strategy, doctrine, and technology through an overarching joint capabilities assessment process and operationally focused acquisition system.

ESSAY REPORTS

ENERGETICS

Since the dawn of time, man has sought to extract power, both physical and abstract, from his environment. In the early half of the 20th century, mankind began to realize the dream of unleashing the power of the atom, first by understanding the essential physics of this new universe and eventually in the fury of fusion reactions, overmatching any conventional explosive power ever imagined. A new lexicon formed to describe this strange new world – quark, quantum, charm, nano, and byte – with a Russian concept providing the underpinning to all of them, ***Energetics*** – a term from the history of electrodynamics, where energy is the fundamental unit of the universe.

Energetics is both the actual and potential power contained in three interactive media, bioenergetics – the power from living matter, psychoenergetics – the power of mind operations, and energetics itself – the power of all energy action and relations in inert matter. Whereas research into the first two areas is minimal, the third media of

energetics is enjoying a renaissance of investigation, albeit within the cloisters of governmental research laboratories. The focus here is on one component of this research, weapons, and in particular an exemplar system called the Small Diameter Bomb. The essay is in three parts; explosives, sensors, and proliferation and answers these questions, "What is the small diameter bomb?" and "Why is it important?"

Explosives. The first known explosive was black powder, developed in China over a thousand years ago. It used potassium nitrate (KNO_3) as its principal energetic material. Since that time, explosives have advanced greatly in power, but they continue to be largely based on organic nitrate compounds ($R\text{-}(NO_3)\ x$) for their explosive energy. Explosives are broken into the categories of high explosive (HE) that detonates and produces a shock wave that moves faster than material can be forced out of the way, and low order explosives, which deflagrate and produce force waves which move slow enough to push materials ahead of them. High explosives are of primary interest in weapons as their shock waves shatter materials around them regardless of the strength or flexibility of the material.

Essentially all the research in the United States in the field of high explosives is done by government laboratories, or by researchers on contract for government laboratories. This is because there is no major market in the United States for high explosives outside the US Government, excluding the dynamite and specialty construction/demolition fields. The commercial explosives industry in the United States is focused on mining applications where deflagrating low explosives are of prime concern. Currently, there is only one producer of RDX in the United States, the Holston Army Ammunition Plant (HAAP) (Hix, 198).

The focus of governmental laboratories has mainly been on new composite explosives based on the existing core energetic compounds. There are two driving forces behind these research directions. Conceptually, the "kill chain" for munitions contains the guidance, fusing, and energetic materials aspects. The sum of these parts is needed to cross a given threshold to achieve a kill. With regard to the tradeoff between precision and effects, if the guidance to target is inexact, or the fusing not precise, then a larger explosive load is required to ensure the desired effects. With the advent of precision guidance and fusing, munitions can be delivered close enough to target that large warheads are no longer required to ensure a kill. However, smaller warheads require that the destructive effect of the energetic material be delivered with more precision. For example, if a fragmentation effect is desired, then an explosive that expends the majority of its energy in concussion may not produce the needed kill capabilities at target. Since homogenous energetic materials do not vary much in the way they expend their energy, composites are need to "tailor" the effect of a small warhead for each purpose.

The second focus for research stems from desire to ensure munitions do their damage always and only when intended, regardless of the stresses to which they are subjected. Sympathetic detonation, due to accident or enemy fire has produced tragedies in all the services. There are shock and friction sensitivity requirements needed in energetic materials for ultrasonic penetrations of hardened and deeply buried targets that cannot be mitigated. These two concerns together produce a requirement for powerful energetic materials that are insensitive to unintended detonation.

As was noted earlier, the currently used core energetic materials are more sensitive to impact and friction than TNT, yet they provide the increased power that smaller, more precise, munitions require. Research into ways to reduce the sensitivity have included wax and polymeric bindings of RDX, in concert with grain polishing of the core energetic material that has halved the sensitivity to impact detonation. Work such as this, along with work on other composite explosive formulations have produced materials with the desired power and insensitivity requirements.

Research at the various labs continues to be in the direction of increased power with decreased sensitivity, and with other properties for tailored characteristics. The major issue with the industrial base is that there is effectively no commercial base for research. The US government owns or operates the majority of the energetic material production, explosive material storage, munitions production and filling capabilities. This being the case, there is only limited commercial research and development capability for the government to leverage. As evidence of this, the fact that patent for CL-20, arguably the only new core explosive to be produced in the recent past belongs to the US government (NAWC, 2).

A compounding problem is the potential irreplaceable loss of experienced workers. As noted there is no commercial knowledge base from which to draw. The workers in the government labs are approaching retirement age en masse. As these retirements begin, the danger exists that the United States will lose the majority of its explosives industrial base. Although some effort has been made to hire and train workers in these areas, it is not clear the effort will be sufficient.

Exacerbating this loss of workers is the fragmentation of effort that is a result of disparity in funding procedures for research on explosives at DoD laboratories. The Navy and Army labs currently receive funding for specific programs in response to service needs. However, there is no continuous, reliable funding line for basic research at other than US Air Force research labs. The consequence of this is a natural competition between the labs and a lack of completely open sharing. These labs perceive themselves in competition for the same resources to some degree, and view complete openness as a threat to their competitive advantage. Since we have no commercial research base to draw from, it is imperative that we ensure all the labs receive some fixed amount of money to guarantee continuing basic research.

There are also issues with certain basic materials. As is the case with RDX, there is only one major supplier of Ammonium Perchlorate in the US. A catastrophic failure (as has occurred in the past) at one of these plants could threaten replenishment of military needs in wartime. In conclusion, it appears that the production, availability, and research and development of energetic materials is only marginally capable of supporting national security in the future, and may fail altogether if not given attention and assistance.

Guidance. During the Vietnam War, bombing accuracy was improved through laser-seeking optics combined with a moving fin attachment to guide the bomb to a target being lased. This invention created the first family of precision bombs called *PAVEWAY*. In the 1990s, the laser-tracking and television-guided family of weapons added a new capability, Global Position Satellite (GPS) guidance, adding an all weather capability and greater flexibility to the sensor systems. Today, the latest generation of precision

munitions, which includes the Joint Direct Attack Munitions (JDAM), uses a combination of GPS and Inertial Navigation System (INS) electronics to enhance the accuracy of bombs, achieving a ninety percent probability of impact within 13-meters of the target area. This accuracy factor or Circular Error Probability (CEP) is expected to decrease by using new signal processing software and further miniaturization of sensors to allow reception of additional GPS signals on multiple, secure communications channels (Hewish, 1).

The Small Diameter Bomb Program (SDB) uses enhanced GPS/INS electronics and software along with anti-jamming system electronics with differential GPS to increase the accuracy of the bomb to demonstrated CEP accuracies of about one to three meters. With this improved accuracy, the total bomb weight (explosives less than 20% of total weight) is a 250-pounds instead JDAMs 500, 1000 or 2000-pound bombs (weight is case and explosive). The initial version of the SDB will be for stationary targets with future variants designed for moving targets. The next spiral development of the SDB will focus on moving targets and will require an additional terminal seeker in addition to the GPS/INS electronics. This may include a two-way data link to provide Bomb Impact Assessment (BIA) as a real-time system to provide initial feedback on target engagement and weapon effects (AFRL, 18).

The navy has designed a more accurate front-end seeker, Direct Attack Munitions Affordable Seeker (DAMASK) that is a GPS/INS system with an infrared front end for terminal guidance (last several kilometers of flight) for stationary targets (three meter CEP-DAMASK and JDAM). The un-cooled infrared seeker used is a dual use redundant device used on Cadillac cars. With this dual use technology, the seeker price per bomb is approximately $10,000.00, or half the cost of current GPS sensors (JANES (DAMASK), 1). With dual use technology, the potential exists for other nations to gain and exploit this technology for their own use. It is not known at this time if this device could be tailored for moving targets. The next generation of PAVEWAY family of bombs will incorporate GPS/INS with the laser seeker of the system. Other variants of additional seekers that can be used as an adjunct to the GPS/INS system for terminal guidance are several types of radar and different colors of infrared. With enhanced electronics, these weapons should be able to provide the capability to target moving targets.

As the accuracy of weapons increases and the bomb explosive material changes, analysis techniques may have to change. We have seen during Operation Iraqi Freedom (OIF) that a cruise missile was able to target a specific floor of a building for destruction. With increased accuracy and bomb material variants, analysts will want to look at soft kill options versus hard kill options. For example, if a bomb could produce sufficient localized energy for an Electromagnetic Pulse (EMP) effect, a specific floor of a building could be targeted to debilitate electronics. Or planners could target the electric power lines for that specific building instead of the entire power grid. The planner and/or analyst will need more information about what targets need to be debilitated and to what degree.

The Global Positioning System (GPS) continues to evolve in quantity of satellites within the constellation as well as the electronics in the Block IIR and future Block III satellites (IDR, pg. 2). The Block III satellites have the requirement to increase transmission security by including a selective anti-jamming system and incorporating additional frequency bands, from two in current GPS satellites to five and with four times

the signal strength. The new module will replace the precise positioning service security module within receivers that generate the pseudo-random noise (PRN) needed for differential calculations and precise navigation. It enhances operational capability in at least three ways, 1) Advances in cryptography, 2) the creation of a tamper-proof security boundary for the receiver's electronics and software, and 3) Greatly reducing an enemy's ability to derive useful information from captured units. The crypto-key architecture allows GPS hardware to remain classified after keying; and receivers can acquire the military-grade precision signals directly in place of PRN substitutes. Additionally, GPS satellite orbits can be adjusted to assist operations in theater for specific war fighting requirements (Enge, 80).

The accuracy improvements of the GPS constellation are important. However, when employing weapons such as the SDB, using differential GPS combined with multiple receptors to negate jamming, the errors associated with targeting become not the weapon, but the interpretation of targets. Therefore, accuracy in programming weapons – especially if conducted dynamically while in flight - and the movement of targets, become critical factors in achieving the desired operational effects.

Proliferation. While the components of explosive filler and advanced sensors along with intelligence and operational art redundant may seem simple, it is the fusion of these elements along with the industrial base that leads to the final questions, "Can other nations or industries make advanced weapons similar to the small diameter bomb?" and "Can they effectively employ these advanced weapons?" These two questions form the basis of the discussion on proliferation.

Can other nations or defense industrial companies manufacture small diameter bombs? At the purely manufacturing level, the answer is, "Yes." As previously discussed, the explosive filler for the bomb is composed of common materials, and the sensor system is reproducible from parts found in other products, e.g. car navigation systems. However, there are two aspects of the small diameter bomb, and the emerging family of weapons, that are beyond most nations' capability: first, the sensor fusion linking intelligence, targeting, employment, and effects into synthetic battle space awareness operating around the globe, day or night, from ground to space. Second, the ability to deliver these weapons from a staggering variety of platforms, employing everything from legacy bombers, to stealth platforms and unmanned vehicles, to submarines and from orbit. This fusion of dominance, precision, network, and capability has no peer now or for the near future.

In summary, other nations can and will produce advanced precision weapons in the near term future. However, given the ever-growing gap in the percentage of gross domestic product invested on defense procurement between the United States and the rest of the world, the answer to effective employment is, "No." Furthermore, SDB is only a fraction of the emergent kinetic weapons and devices designed to dominate the battlespace in the near-term future.

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NON-LETHAL WEAPONS

Non-lethal weapons will broaden the warfighter's options beyond the threat and employment of lethal force. Non-lethal weapons are promising, particularly in areas of protection and security; limiting collateral damage and non-combatant injury. Non-lethal weapons can either deter or determine intent of opposing forces in a hostile environment.

Research and development of non-lethal weapons range from low- to high-end technology. Currently, low-end, kinetic, blunt-impact non-lethal weapons are attractive to both the military and commercial markets. Because of their relative maturity, affordability, and acceptance, low-end rather then high-end non-lethal weapons will dominate non-lethal employment in the near future (1-5 years). Although still relatively immature, with increased DoD commitment, greater operator awareness, and broader public acceptance, directed energy will emerge as the non-lethal weapon of choice within the next two decades.

Currently, the US military is using non-lethal weapons in Iraq. These include: rubber, sting ball, and flash-bang munitions; pepper spray; high intensity lights, and long-range acoustic systems. Possible future (10-20 years) military applications include: high-powered microwave systems; electromagnetic pulse and radiation systems; and various laser applications.

The Department of Defense is the US leader in non-lethal weapons development. DoD Directive (DODD) 3000.3 defines non-lethal weapons as, "weapons that are explicitly designed and primarily employed so as to incapacitate personnel and material, while minimizing fatalities, permanent injury to personnel, and undesired damage to property and the environment (DODD, 2)". Non-lethal weapons are designed to have relatively reversible effects on personnel or material.

International conventions and treaties limit development and possible employment of non-lethal weapons. Some of these aging regulations may need review for applicability in consideration of developing non-lethal technology.

Directed energy non-lethal weapons. Independent initiatives and innovativeness of small commercial businesses and US military laboratories are defining the future of directed energy non-lethal weapons. The majority of directed energy research remains focused on lethal application of high-powered lasers such as in missile defense, force protection from indirect fire, and counter-material capabilities. Non-lethal applications of directed energy have a different focus. The intent is not to destroy or even injure permanently. The non-lethal intent gives the war-fighter an additional option, increasingly important for peacekeeping and nation-building operations. In the long-term (10-20 years), directed energy, non-lethal weapons will incorporate such exotic technologies as ultraviolet radiation, ultra- and infrasound. Based on the current state of technology, the direct use of high-energy laser and particle beam weapons remains highly lethal; therefore not suitable for non-lethal application. However, there may be applications where indirect employment of such technologies (i.e., stimulating plasma fields, creating an ionized path to the target) can produce a non-lethal effect.

Logistics requirements. Logistics is a key part of any military plan, to include fielding new weapon systems. The bulk of a system's cost is in the sustainment portion of the life cycle. Supportability, transportability, and other related logistics concerns are critical when considering development and fielding of non-lethal weapon systems.

High-end non-lethal weapons include complex, technical power systems, which challenge even the most familiar contractor maintenance personnel. Some maintenance requirements will require return to manufacturer for repair, or extensive technical training of military forces. Additionally, combat operations require non-lethal systems to withstand extreme temperatures and austere environments.

Current research and development of non-lethal weapons is in the prototype stage, and supportability issues have not yet been addressed. Logistics support is currently an after-thought, and requires DoD emphasis before employment planning.

Roadblocks. Numerous roadblocks are delaying non-lethal weapons employment. There is an absence of stated war-fighter requirements for this capability. Neither combatant commanders nor the services have prioritized these weapons in the form of hard requirements. Lack of valid requirements and command priorities limit robust, consistent funding. Using limited available funding, developers, in an inefficient haphazard fashion are trying to anticipate the war-fighter's need.

A critical constraint in rapid fielding of non-lethal weapons deals with policy for their use, specifically consideration of human effects. The question is how much risk will we accept in order to get capability to the war-fighter? DODD 3000.3 definition of non-lethal weapons requires minimum permanent injury and fatalities. It may be that we should consider the potential of unintended blindness, for example, as a reasonable trade-off to war-fighter security and/or the use of lethal force.

Multiple agency involvement in non-lethal weapons efforts within DoD is a roadblock leading to separate initiatives, and possible duplication of effort. A small budget and staff limits the overall ability of the Joint Non-Lethal Weapons Directorate to govern or champion joint non-lethal weapons development. This dysfunctional approach to procurement hampers technological development by commercial industry. The ability to produce high-powered acoustics, microwave, and laser systems will take additional time because most of the supporting industry is prototype versus production orientation.

Lastly, non-lethal weapons research and development is constrained by the international scrutiny of treaties and conventions. Non-lethal technology may call into question the validity of some 100-year-old antiquated international laws.

Foreign proliferation. Development of non-lethal weapons is increasingly important to most industrialized nations (NGIC, 1). Areas of interest include: kinetic impact weapons, nets and entanglements, incapacitating chemicals, electromagnetic/RF weapons, anti-personnel and anti-material weapons, and lasers (NGIC, 1). Currently, the United States has an advantage in some forms of high-power microwave (HPM) non-lethal weapons. No other country has invested the same amount of resources as the US in these systems, but they continue to research other forms of non-lethal directed energy weapons, attempting to leverage the RF and HPM environment.

Germany continues to do extensive research in the high-powered microwave arena. A prototype vehicle mounted laser designed to neutralize modern digital

electronics is in the final stages, and could be ready for prototype testing in 2006 with possible service employment in 2012 (Foss, 1). The United Kingdom and US DoD are partners in a British-designed high-power RF directed energy weapon that is closer to operational use than either the microwave or laser technologies developed independently by the US. In addition to RF energy weapons, the UK is actively pursuing the development of a HPM weapon designed for use against command and control, communications, and air defense assets. The Israeli Ministry of Defense, in cooperation with the US Army and Northrop Grumman, has signed off on a mobile tactical high-energy laser (MTHEL) prototype. This transformational tactical weapon will be the first mobile directed energy weapon capable of destroying tactical airborne threats in midair (Gildea, 1).

Many other countries are interested in the development of non-lethal weapons. According to current research, the United States enjoys an advantage in HPM systems. However, countries such as Germany, UK, and Israel are aggressively developing weapons in the RF and HPM arena. The US will not maintain its technological advantage without proactive DoD leadership and robust funding in the out years.

Conflict with laws of war. US defense firms cannot afford to risk stockholders' investments and employees' livelihoods by venturing, unprotected, into the development of non-lethal directed energy weapons. Like conventional weapons, non-lethal weapons undergo legal review before development and employment. DoD provides a fair and reasonable degree of indemnification by virtue of thorough legal and treaty compliance review conducted by the department and individual Services. Because of these reviews, US firms working with DOD do not fear direct liability and therefore are not hesitant to develop non-lethal directed energy weapons technology.

US military forces in armed conflict cannot use weapons or weapons systems before they have successfully completed a legal review process. Non-lethal weapons require the same review as lethal weapons (DODD, 1). DoD legal review of non-lethal weapons involves a three-part test. First, the weapon must not cause unnecessary suffering to accomplish legitimate military purpose. Second, the weapon must be controllable in a discriminatory manner in which combatants are distinguished from civilians. Third, the weapon must not violate specific treaties or laws prohibiting its use or restricting its employment. This legal process ensures non-lethal weapons are consistent with US obligations under customary international law, war treaties, and arms control agreements.

The perceptions and reactions of the domestic and international public, non-government organizations, and the media will have political and social influence on future production and employment of non-lethal weapons. DoD should initiate an aggressive public affairs campaign now, detailing legal policy and human effect issues surrounding non-lethal directed energy weapons to minimize unwarranted criticism and misperceptions that slow the maturity or employment of this technology.

Force Transformation. Non-lethal weapons will dramatically change how forces operate in urban conflict where combatants mix with non-combatant civilians. Non-lethal weapons provide a discriminatory response during force, structure, vessel, vehicle, or area security and protection. Non-lethal weapons can either deter, or easily

identify the intent of individuals or groups at an extended range allowing friendly force appropriate response.

Non-lethal weapons will be a force multiplier providing wide area, long-range security, reducing requirements for strained security and police forces. Joint interagency employment will transform the interoperability of US military civil support operations. Existing civil support teams equipped with non-lethal weapons will have the capability to contain large weapons of mass destruction contaminated areas.

True transformation will come from joint incorporation of multiple non-lethal weapons systems within all US military and government agencies. During research and development, there is no system-of-systems thought. Joint policy, doctrine, and training must incorporate multiple non-lethal systems for exponential capabilities. Additionally, the US military must transform to a view of non-lethal to lethal weapons. Technology exists to develop high-end directed energy weapons scalable from non-lethal to lethal. One stun-to-kill weapon will have limitless transformational effect on all US military and agency forces. Transforming energy to ammunition equals refueling becoming rearming. One weapon, demonstrating all options, equals transformation.

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CONCLUSION

The study of the weapons industry, albeit represented by limited segments discussed in this report, distills down to one last question, "What does this mean to the national security policy of the United States?" Although we could expend many pages of text attempting to answer this question, the chart in Figure 4 best illustrates our response. The chart depicts the intersection of comparative advantage versus capabilities for the three segments we studied, plus the plot for precision weapons, located at a much higher intersection point. If we were to plot the relative intersection points for our nearest competitor or ally, we would see a close match in terms of small arms and non-lethal, but no points approaching US capabilities or advantage in precision munitions or energetics. We believe the message from our study and this chart is clear - we risk losing our relative comparative advantage in small arms in the near future unless focus in the form of doctrine, technology, and investment is made. Given our overwhelming advantage in precision weapons, we can tolerate the risk of re-allocating limited funding from these programs to support small arms, the maturation and employment of non-lethal technologies, and the exploitation of advanced energetics. The impact will be felt from the tip-of-the-spear – our combatant forces – to the highest levels of national policy.

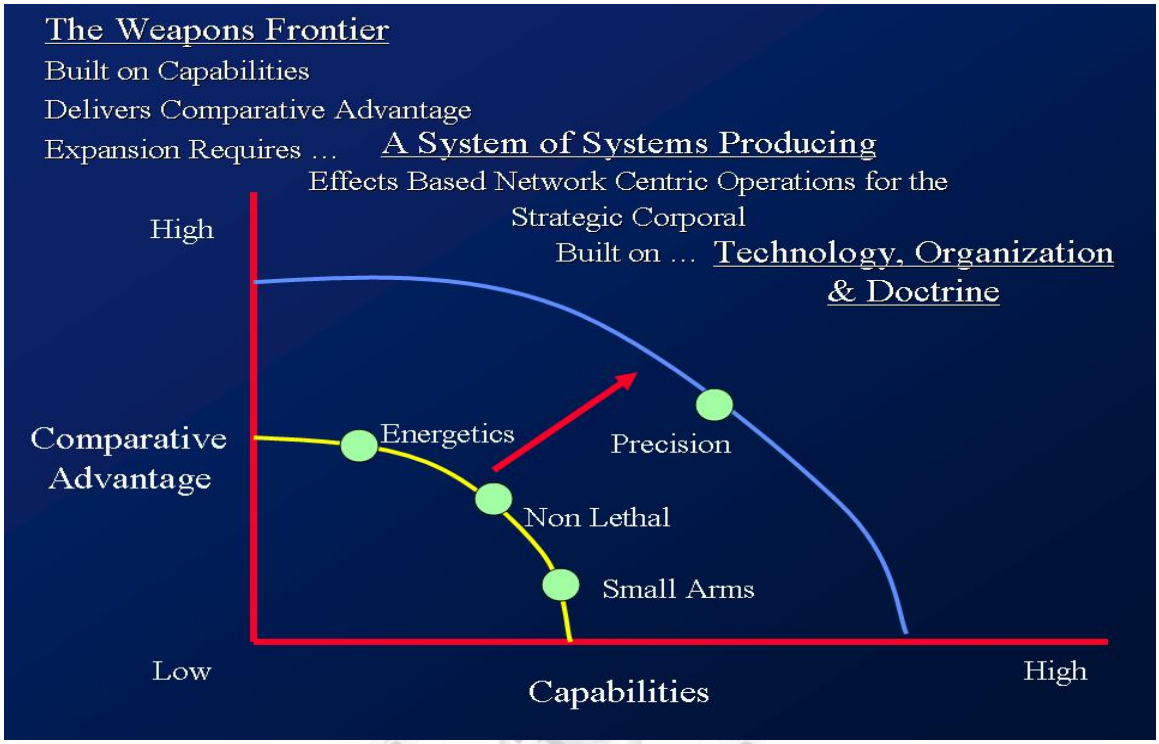

Figure 4 - The Weapons Frontier

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