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THE IMPACT OF NANOTECHNOLOGY ENERGETICS ON THE DEPARTMENT OF DEFENSE BY 2035

by

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Table of Contents

Table of Figures

BIOGRAPHY

Colonel Yarbrough is currently a student at the Air War College, Maxwell Air Force Base Alabama. Prior to the College, he served as the Air Combat Command F-16 Program Element Monitor and Weapon System Team Chief at Langley Air Force Base, Virginia. He has participated in or directly supported numerous combat operations including Operations DESERT SHIELD, DESERT STORM, IRAQI FREEDOM and ENDURING FREEDOM. His military positions include 27th Fighter Wing Chief of Safety, Lead Contingency Air Planner at United States Joint Forces Command and Chief of Staff, Air Component Command Element - Afghanistan. He holds a bachelor's degree in aeronautical engineering from the United States Air Force Academy, a master's in aeronautical sciences from Embry-Riddle Aeronautical University and a master's in military arts and sciences from the United States Army School of Advanced Military Studies. Colonel Yarbrough is a Command Pilot with over 2500 hours in the F-16 and F-111.

Introduction

New weapons of warfare call for the total and radical reorganization of methods of warfare, and he who falls asleep during this process of reorganization may never wake up.

Soviet Marshal Mikhail Tukhachevskiy, circa 1932[1]

Why Nanotechnology and Why Now?

Nanotechnology will have a profound impact on the profession of arms by 2035. Breakthroughs in this burgeoning science will foster the miniaturization of weapons, decrease the cost of space launch systems, and make resilient rechargeable battery power readily available. The U.S. Department of Defense must embrace nanotechnology research and development in order to capitalize on these developments. Preparing for new nanotechnology-inspired weapons will provide the depth of technological understanding required to field new systems and to adequately deter nations, non-state actors, and individuals that may attempt to use nanotechnology in malevolent ways.

It is important to precisely define what is meant by "nanotechnology" as this term has come to have many different meanings to different elements of the scientific community. Nano is a scientific prefix meaning one-billionth (10^{-9}); a nanometer (nm) is one-billionth of a meter. The United States National Nanotechnology Initiative (NNI) definition of nanotechnology will be used for this paper. The NNI defines nanotechnology as technology in the 1 to 100nm range where unusual physical, chemical, and biological properties can emerge that may differ in important ways from the properties of bulk materials.[2] For reference, 10 hydrogen atoms in a line equal 1nm, human DNA strands are 2nm wide and a human hair is approximately 75,000nm wide.[3] Transistors on the latest computer processor chips are spaced at 45nm.[4]

Nanotechnology implies working at extremely small scales to unlock capabilities that are unique to the intermolecular level. At this scale, there are quantum effects to be exploited including strong electrostatic covalent bonds and ferromagnetism (cooperative state of matter where magnetic moments are locked in parallel, leading to macroscopic magnetization).[5] Nanotechnology provides the scientist and engineer methods to select and design properties of new materials for manufacture that were never before available.

Nanotechnology will revolutionize engineering, manufacturing, processed goods and services, and certainly military systems. That things will continue to "shrink" is a given. Indian President A.P.J. Abdul Kalam recently proclaimed, "The next ten years will see nanotechnology playing the most dominant role in the global business environment and is expected to reach one trillion dollars."[6]

Nanotechnology research provides a ready example of Thomas Friedman's theory that the world has grown flat due to global linkages. Many nanotechnology technical papers are collaborative endeavors between scientists from different nations[7]. Cutting-edge scientists are sharing nanotechnology knowledge and techniques in hard sciences such as chemistry, biology, and physics.[8] Their research is opening doors to interdisciplinary discovery that is shared by developed and developing nations alike. This fosters a natural proliferation of nanotechnology. No nation or alliance will be able to restrain nanotechnology advances and no nation is likely to corner the market.[9] For this reason, the breakthroughs that will impact military technologies are of great interest to all.

Competition between nations and industries to find major breakthroughs in nanotechnology will lead to cost reductions and proliferation, an eventuality for which militaries must prepare.[10] Many nations and industries are currently funding intense scientific research to find the major breakthroughs that will reduce costs and improve products by orders of magnitude.[11] Development will accelerate as engineers around the world discover new techniques of working at the nano scale. Military professionals must anticipate rapid technological development and develop strategies to incorporate the discoveries. Militaries without nanotechnology will be at a disadvantage when faced with a nanotech-armed adversary. Nations must endeavor to field nanotechnology and must be prepared to deter or defend against it. Otherwise they run the risk of meeting a far superior foe in the time of crisis.

Nanotechnology Today and Tomorrow

Nanotechnology is currently more concept than practice, but this will change swiftly due to large research investments by developed countries and the payoff for turning concepts into reality. Jovene showed that $4.1B had been invested in nanotechnology worldwide by 2005 and that by 2007 the United States was investing $3.0B annually.[12] While research and development are initially quite costly, the products themselves will be less costly than those they replace owing to their size and increased qualities and capabilities. A quick comparison can be made

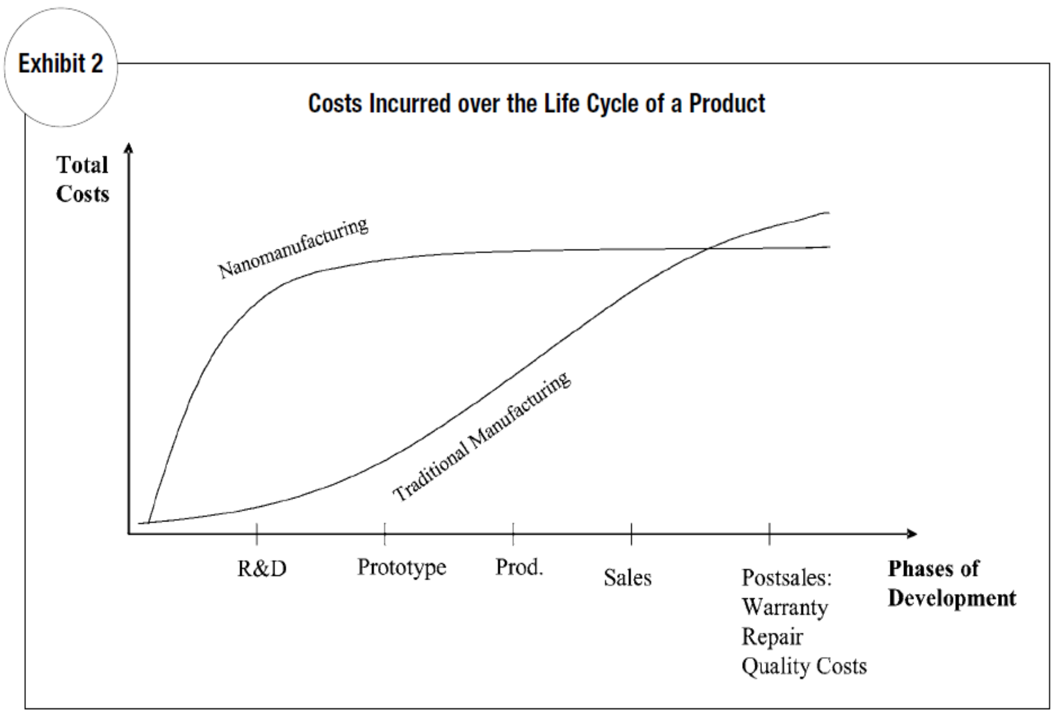

Figure 1: Cost Comparison of Nano to Traditional Manufacture[13]

to integrated circuits. Over the last 40 years they have become dramatically smaller, far more capable, and much cheaper. Hailed as the next revolution to redefine electronics, nanotechnology is postulated to similarly change virtually every industry in the public sector.[14]

There are numerous industrial examples of how nanotechnology is affecting properties of materials used in current products. Nano-porous silicon is a stable reactive material that is being valued for its use in vehicle airbag initiation. Vehicle impact opens pores to each other creating

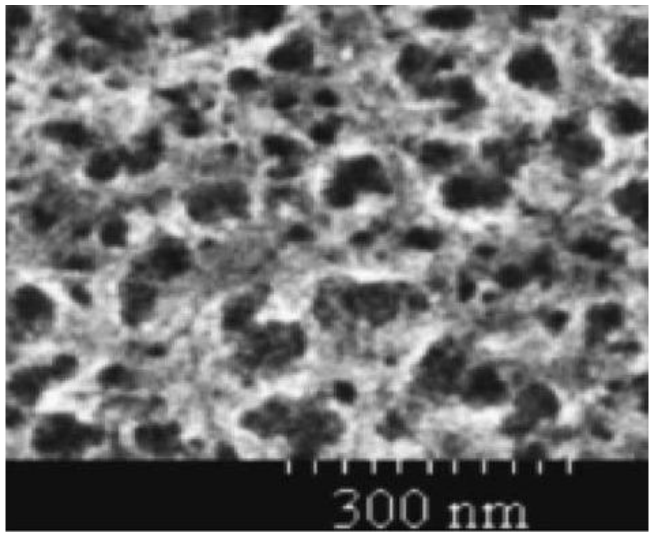

Figure 2: Nano-porous Silicon Top View[15]

a highly reactive micro-explosion deploying the airbag.[16] Researchers are using nano-nickel to reduce the weight of batteries. One-eighth the cost of platinum, nano-nickel can be utilized in fuel cells surviving ten times more recharges than platinum with far less weight due to the thin durable nano-nickel membranes.[17] Nano-alumina particles have been dispersed in copper improving hardness by 50 percent, while maintaining good electrical conductivity and without softening even at temperatures approaching the melting point of copper.[18] These are just the leading edge of nanotechnology's impact.

Scientists are actively researching how to create core structural properties of materials by utilizing nano-sized particles. A staple of structural research is the carbon nanotube (CNT), a naturally self-organized nanostructure (1-2nm width) in the form of a tube comprised of carbon atoms with completed bonds. Carbon nanotubes have 100 times the tensile strength and 5 times the lateral strength of steel, and can be designed to have electrical conductivity up to 10 times that of silver, all at one-quarter the density of steel.[19] CNT properties can be altered by how many carbon atoms are present and by their chirality (alignment twist and bond geometry).[20]

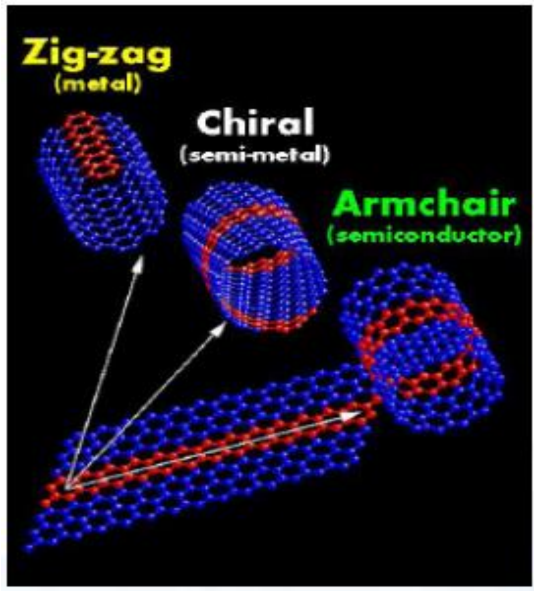

Figure 3: Three Forms of Carbon Nanotubes Based on Chirality[21]

Carbon nanotubes can be semiconducting like silicon or conduct electricity better than copper,[22] and they rank among the strongest materials known.[23] Scientists are exploring the many outcomes of doping CNTs with different atoms to gain unique properties.[24] The difficulty in this endeavor is controlling CNT formation to achieve consistent, desired properties. By 2035 CNTs will yield tremendous advances for mankind and will greatly alter military relevant technologies and systems.

Nanotechnologies with Greatest Military Impact

Nano-Energetics: Explosives and Propulsion

Energetics is the application of technology to alter the design of power sources, propulsion and explosive combustibles. It is most commonly associated with increasing their energy density. Historically, advances in energetics have radically altered military operations. For example, the use of rapid loading smokeless powder in the 1898 Spanish-American War made the American Navy far more powerful than the Spanish Armada; a mix of powdered aluminum and gum slurry, hardened into a grain propellant, allowed creation of sea-launched ballistic missiles in the 1960s that were crucial to Cold War deterrence; in 2005 the thermobaric bomb provided American forces unique targeting capabilities by produced devastating pressures in deep and winding tunnels in Afghanistan.[25]

Nano-energetic materials (nEMs) have improved performances compared to larger materials as they have more surface area per volume than traditional powders.[26] They increase the speed of reaction, providing quicker ignition creating larger energy releases in a shorter amount of time. "Nano-energetic materials have shown improved performances in terms of energy release, ignition, and mechanical properties compared to their bulk or micro counterparts.[27] In MIC [metastable intermolecular composites], oxidizer and fuel are mixed at the nano-scale, thus leading to the enhanced reactivity caused by the reduced mass transport limitations between the reactants."[28] Researchers can greatly increase the instantaneous explosive power of current explosive reactants by adding superthermites[29] (most commonly nano-aluminum based) to their composition which increase the rate of their overall oxidation and resultant explosion.[30]

Nano-energetic materials react faster than larger molecules with the added benefit of increasing safety and dependability. With some compounds simply nano-sizing has increased safety margins by 33 percent while preserving the reactivity proclivity. For example, 5-Nitro-2,4-dihydro-3H-1,2,4-triazole-3-one (NTO) is a nano-derived compound with high energy and far less sensitivity.[31]

Another method of increasing safety is to incorporate silicon with specially tailored nanowires with nEMs. "The [manufacturing] process uses standard micro-fabrication technologies and therefore it is suitable for mass production. The MICs are deposited onto silicon, a basic material for micro-electronics and micro-systems. Consequently, it is straightforward to integrate the MIC into micro-systems to result in nanostructures, for example, high-performance nano-igniters."[32] For the near term this will provide current weapons with dependable, fast ignition sources. But in the future the technology will no longer be just an additive.

Researchers at the University of Maryland are utilizing a new nanothermite mixture ($Al/KMnO_4$) to gain two orders of magnitude greater reactivity than traditional igniters. They are pioneering techniques for synthesizing core-shell nano-structured composite particles as a means of controlling the reactivity.[33] New weapons systems will be designed around nano-materials specifically created for desired explosives characteristics. Aluminum is not the only metal being explored. Nano-boron exceeds the explosive heat of aluminum.[34] Preliminary research is paving the way to fine tune and control reactions with different metals in nEMs.

Researchers are busily working on nano-sizing current conventional explosive materials with eyes on increasing not just controllability but explosive potential. The limitation has been the ability to create quantities of nano conventional compounds such as RDX ($C_3H_6N_6O_6$). One new technique is to form the explosive reactants by multiple nano-blasts forming calcinations of the material. This procedure produces a highly stable nano-sized RDX powder with excellent structure and increased energy release potential.[35] The highly energetic impacts of the blast waves create extremely high local temperatures that prevent impurities and unwanted oxidation of the compound. These and other efforts aim to exploit quantum effects of chemical compounds that are beyond their characteristics in bulk.

Nanotechnology "could completely change the face of weaponry," according to Andy Oppenheimer, a weapons expert with analyst firm and publisher Jane's Information Group.[36] First will be weapons that maximize precise explosion properties (e.g. blast, fragmentation) for specific mission-oriented weapons. These weapons will utilize superthermite detonators in conjunction with traditional explosives. Superthermite detonators can be used in refurbishing current stockpiles of nuclear warheads. Oppenheimer asserts that nations are currently researching and developing devices that use nanotechnology to create much smaller nuclear detonations.[37]

By 2035 nano-energetics will have advanced to replace current explosive materials and systems designed to deliver them. They will provide the explosive power of current conventional weapons at up to two orders of magnitude less overall mass. Weapons designers will capitalize on the molecular interactions that can be carefully constructed from the bottom up in combustible nano-materials, and a new class of very small, extremely lethal weapon system will emerge. Illinois University Prof D. Scott Stewart is postulating how to scale weapon systems down by a factor of 100 to 1000 which would essentially become micro attack devices.[38] These new weapons will be cheaper due to their size and amount of material used. The affordability and capability of such weapons will ensure their proliferation and worldwide availability.

Small enhanced explosive systems will be more easily hidden than traditional explosives. Adversaries will take advantage of their size, lethality and portability. Enhanced concealment will pose a significant challenge to militaries and law enforcement. There is no limit to the creative ways of disguising nEM explosive charges.

Another second order effect of smaller more lethal weapons is shrinking delivery vehicles. Smaller warheads require less support structure. These smaller structures will contain nano-alloys for enhanced characteristics yielding lighter mass and less volume. Smaller structures and lighter warheads require less propellant to get to the intended target. MICs will have a radical effect on rocket and gun propellants.[39] The more powerful nEM propellants will further reduce the size of munitions. Altmann concludes that advanced energetics when combined with nano-composites will yield vast changes for military weapons systems and capabilities.[40]

Advances in nanotech propulsion will be in lock step with nEM explosives. Nano-energetics will have a profound effect on rocket technology. Propellant nEMs will have higher energy density for overall rocket mass than separate rocket structure and classical propellants. Scientists are working to enhance solid and air breathing rocket motors through nEMs. Researchers at Los Alamos National Laboratory experimented with nitrogen energized nEMs to determine the impact on air-breathing rockets. "Nano-particulate aluminum metal was added to the high nitrogen energetic material triaminoguanidinium azotetrazolate (TAGzT) in order to determine the effects on decomposition behavior."[41] They found that nano-Al reduced the required pressure for the TAGzT reaction while increasing the heat release, providing faster energy release. Researchers are also making progress in nEMs to solve solid propellant inefficiencies. "The use of nano-Al powders for solid rocket propellants appears feasible and advantageous."[42]

Initial research into ALICE (aluminum-ice propellant) foretells the future of nanotech propulsion. Researchers at Purdue University successfully launched miniature rockets to heights of 1300 feet utilizing nano-scale particles 500 times smaller than the width of a human hair.[43] Whereas micron size particles did not work, nano-sized particles did work due to their increased surface area per volume. "Nano-aluminum provides ultra-high burn rates for propellants that are ten times higher than existing propellants," says Doug Carpenter, the chief scientific officer at nano-metals company Quantumsphere.[44] Quantumsphere is pioneering research into nano-energetics. The impact for space access will be immense.

Decreasing the propellant required to move a given payload greatly alters overall rocket mass.[45] The typical single-stage space rocket is 90 percent propellant, 6 percent structure, and 4 percent payload while multi-stage vehicles have more structural mass with a corresponding mass fraction (ratio of propellant to overall mass) of approximately 0.8.[46] Doubling the specific impulse (I_{sp}, the change in momentum per unit of propellant) of the rocket fuel decreases the nominal mass fraction from .8 to .66 allowing up to a 40 percent overall mass reduction of the

Specific Impulse	Mass Fraction	Overall Mass Reduction
X	0.8	
2X	0.66	40%
4X	0.5	60%
10X	0.29	72%

Figure 4: Effect of Propellant Energy Increases on Rocket Mass[47]

rocket. Nano-alloys utilizing CNTs could further reduce rocket structure mass owing to CNTs strength and density. Considering a constant payload, it is easily conceivable that the combined effect of greater I_{sp} and CNTs could be a 50 percent reduction in required rocket mass. Shrinking payloads based on nano-inspired sensors, batteries and computers coupled with decreased propellant requirements will radically alter the current space launch paradigm.

Nano-enabled solutions will profoundly affect access to space and space systems. Space launches are costly due to weight divided among three variables to which nanotechnology will provide economy-of-scale solutions. First, the payload will decrease in volume and mass due to nanotech-enhanced batteries, miniaturized computers and sensors. Next, the amount of propellant required in terms of mass and volume will be reduced as previously stated. This reduces the size of the vehicle required for lifting the payload into space and also the amount of stored nEM propellant required to maintain orbit. This will make participating in space a much less expensive endeavor for states, and eventually many non-state actors and even individuals will be able to afford it. Light-weight launch vehicles coupled with miniaturized sensors will be military necessities by 2035. Small kinetic-kill satellites will be highly possible. Jurgen Altmann rated this effect "radical" for its impact on space systems.[48]

Nanotechnology and Batteries

Stored energy in the form of batteries is currently the most restrictive limitation on most military systems. They are too bulky, inefficient in terms of preserving charge, and susceptible to catastrophic loss of power. "One of the problems with how batteries are made is there is a large component of the battery that's not active material," according to Dr. Angela Belcher, MIT professor and battery researcher.[49] Belcher is researching nano-materials interfaced with common viruses to produce methods of efficient energy storage and transfer in order to rid batteries of wasted space and weight.

Nano-energetic materials may also provide an answer to energy requirements. "Nanoscale energetic materials (nEMs) particularly offer the promise of much higher energy densities, faster rate of energy release, greater stability, and more security (sensitivity to unwanted initiation)."[50] "Typically, the combustion of propellant produces 5 MJ/kg, while a modern chemical lithium battery used in new laptops only stores 0.5 MJ/kg."[51] Encapsulating nEMs within CNTs would enhance the energy efficiency by adding greater safety, producing an extremely stable, reliable energy source.

Nanotube research also offers promise for new battery materials. They carry and store a greater amount of charge for the same density of material due to their increased surface area per volume and mass. Lithium-ion batteries currently host the greatest density factor. CNTs will increase the anode surface area for greater flow of electrons, pushing energy density factors to ten times existing lithium-ion batteries. Increased surface area will also decrease the amount of time required to recharge. Properly oriented CNTs have extremely high electrical conductivity whereby energy is not lost due to electron scattering or heat dissipation.[52] One square centimeter of conductive plate when coated with nanotubes has a surface area of 50,000 centimeters, compared with 2,000 square centimeters using commercial carbon; the CNTs are extremely conductive, which should increase power output over existing ultra-capacitors.[53] One of the additional benefits is the ability to rapidly recharge CNT ultra-capacitors. Rapid recharge will reduce vulnerabilities and extend useful battery life.

Carbon nanotubes, nanowires and quantum dots are unique nano-structures that allow scientists to take advantage of quantum physics and confinement of electrons to design energy storage and transfer systems that significantly reduce mass, heat loss and resistance.[54] Menlo Park startup, Amprius, has achieved 40 percent greater density in current battery design by using nanowires.[55] A Texas company, EEStors, developed an ultra-capacitor hybrid battery using nano-barium-titanate powders that doubles the energy storage of lithium-ion batteries and is scalable for use in electronics from pacemakers to electric locomotive batteries.[56] Doubling the available power output and storing up to ten times the energy has distinct military implications.

Space based military systems will benefit dramatically from nanotechnology-enhanced batteries. By 2035 nanotech batteries will decrease in size such that they allow miniaturization of space systems. Researchers recently combined a nano-generator with a solar cell to create an integrated mechanical and solar energy harvesting device.[57] This breakthrough will power extremely small devices and be able to produce power in light and dark periods. It portends vast advances for miniaturized earthbound devices and for small space objects. "The possibility of a rapid buildup of space weapons is the most dangerous and destabilizing prospect of 21st century military confrontation."[58]

Nano-inspired batteries will provide reliable power to military weaponry while requiring less volume themselves. Shrinking batteries will enable devices to shrink in size. These new batteries will provide more reliable, readily available power thereby increasing small devices persistence.[59] The smaller devices will be far more concealable owing to their size, reliability, and nano-batteries that provide power in all conditions. They will enable new generations of highly capable advanced mini-satellites, miniature persistent sensors and small persistent mines to exist. Professor Altmann rated energy sources and energy storage as having a significant impact across the breadth of military systems.[60]

Deterring Nanotechnology

Adversaries will covet nanotechnology, especially those advances with significant or radical impact on military systems. "In 2001 the number [of people that a terrorist could kill] reached the thousands, and today we fear scenarios in which tens of thousands might die."[61] President George Bush proclaimed in 2001, "We must build forces that draw upon the revolutionary advances in the technology of war that will allow us to keep peace by redefining war on our terms."[62] Nanotechnology will provide revolutionary advances. The revolutionary

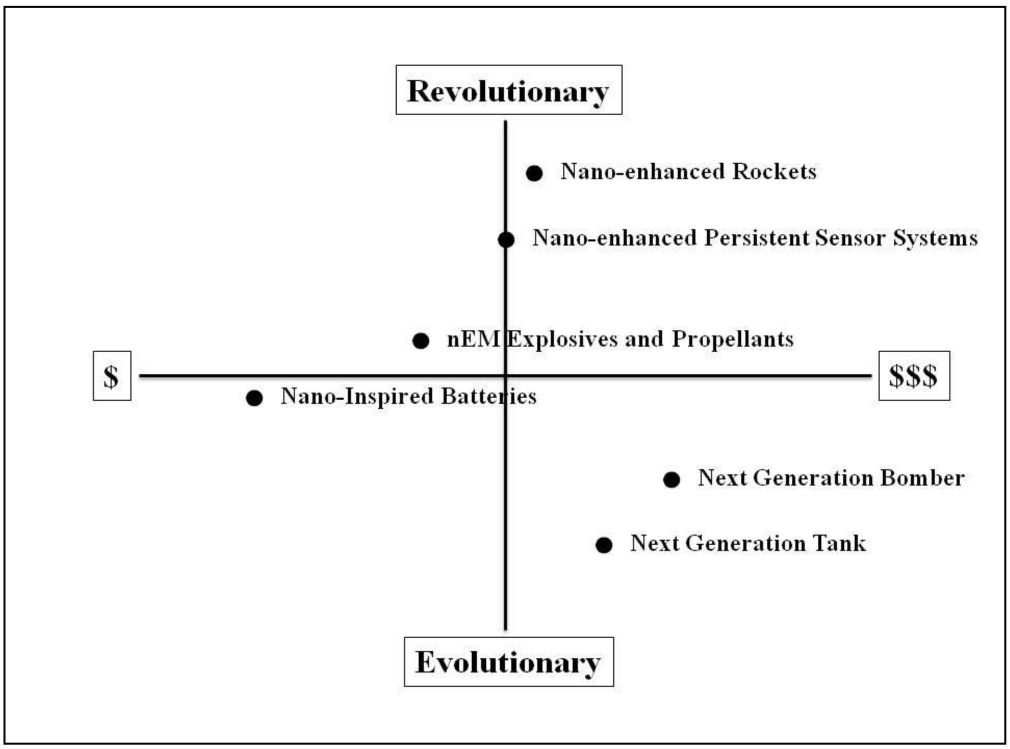

Figure 5: Comparison of Nanotechnology Impact [63]

building blocks (nEMs and nano-inspired batteries) will eventually become quite affordable promoting their proliferation. Worldwide industry will use the same nEMs in mining, drilling and construction while nano-inspired batteries will benefit thousands of electronic devices.[64]

Advanced technological nations will have a vested interest in developing and controlling destructive-capable technologies.[65] Deterring nanotechnology development is not likely and undesirable from an economic standpoint.[66] Companies seeking profits from advanced technology and less developed nations' desire to obtain nEMs will spur nEM proliferation. Nano-energetic materials will be coveted by military forces for their explosive and propellant capabilities while nano-inspired batteries will be desired to shrink system mass and increase system reliability. Nanotechnology enhancements are equally attractive to military and civilian entities along state, non-state and individual lines.[67] "Delay is not feasible (and from a defense perspective it is strategically suicidal, for even if the work [R&D] is not done in the United States, it will certainly continue elsewhere), but regulation, planning, and education are needed."[68] It is far better to understand and possess cutting-edge technology than to guess as to its existence.[69]

Nano-energetic materials and nano-enhanced batteries will transform how conventional wars are fought as they revolutionize weapon systems. Long before swarming micro-devices are possible, nEMs will provide 100 times the explosive power of today's weapons. University of Maryland Professor Mark Gubrud espouses that, "The nanotechnic era will be fundamentally different from the era in which nuclear weapons were developed and came to dominate the possibilities for global violence."[70] He believes traditional nuclear weapons will become obsolete as miniaturized systems utilizing nanotechnology will prevent their use.[71] While that is likely far past 2035, his second contention will occur closer to 2035. He asserted at the Fifth Foresight Conference on Molecular Nanotechnology that nEMs could produce greater proliferation of a new generation of miniaturized nuclear weapons in what would in effect be 4th generation nanotech nukes.[72] For this to occur, nEMs will have to produce significantly more explosive energy than currently postulated or be combined with fissile materials in game-breaking ways. However, Professor Gubrud does open the aperture of what must be considered in terms of deterrence to far more than shrinking weapon systems.

The United States military has historically sought cutting-edge technological solutions for battlefield requirements.[73] Fiscal constraints, however, can limit the ability to harness rapidly evolving technology. Nanotechnology will affect most missions and military tasks, so much so that choosing which new advance or system to fund will prove quite difficult. Nanotechnology advances will not be limited to nEMs and batteries[74]. These are simply the most radical in terms of the military paradigm. Advances in these two fields will lead to exponential change in other fields as they decrease system mass and volume while increasing capabilities. It is completely conceivable that nanotechnology advances will lead to a period of rapid hard-science discovery that outpaces the military's ability to field systems incorporating them.[75]

The U.S. Department of Defense will benefit from increasing basic research in the nanotechnology revolution. Many evolutionary benefits will befall existing weapon systems through spiral incorporation.[76] However, without a more responsive acquisition system, rapid technological change has the ability to make major weapon systems obsolete before they are fielded. Hence, the U.S. Department of Defense is not likely to achieve full spectrum dominance solely by monetary means in a time of rapid nanotechnology advancement.

The U.S. military must seek mitigating strategies to deter nanotechnology systems as a whole, as purchasing defensive systems to thwart individual nano-inspired systems is not feasible. Procuring unique systems to defeat each new nanotech system would lead to military "whack a mole" expenses for high-end technologies that may not come to fruition.

Rather than continually planning to deter the next system, the U.S. should focus on the range of estimated nano-enabled technical capabilities from which proper threat analysis can be conducted (see Figure 6). The range of systems can be categorized to gain meaningful context. The “bins” of capabilities can then be monitored for development, analyzed for lethality and proper counter-measures can be developed. The Department of Defense must focus on the likelihood of nanotechnology incorporation in systems and the associated vulnerabilities across the likely systems to develop mitigating strategies congruent with further developing U.S. military power. The common threads of game-changing nano-enabled weapons are nEMs and nano-batteries.

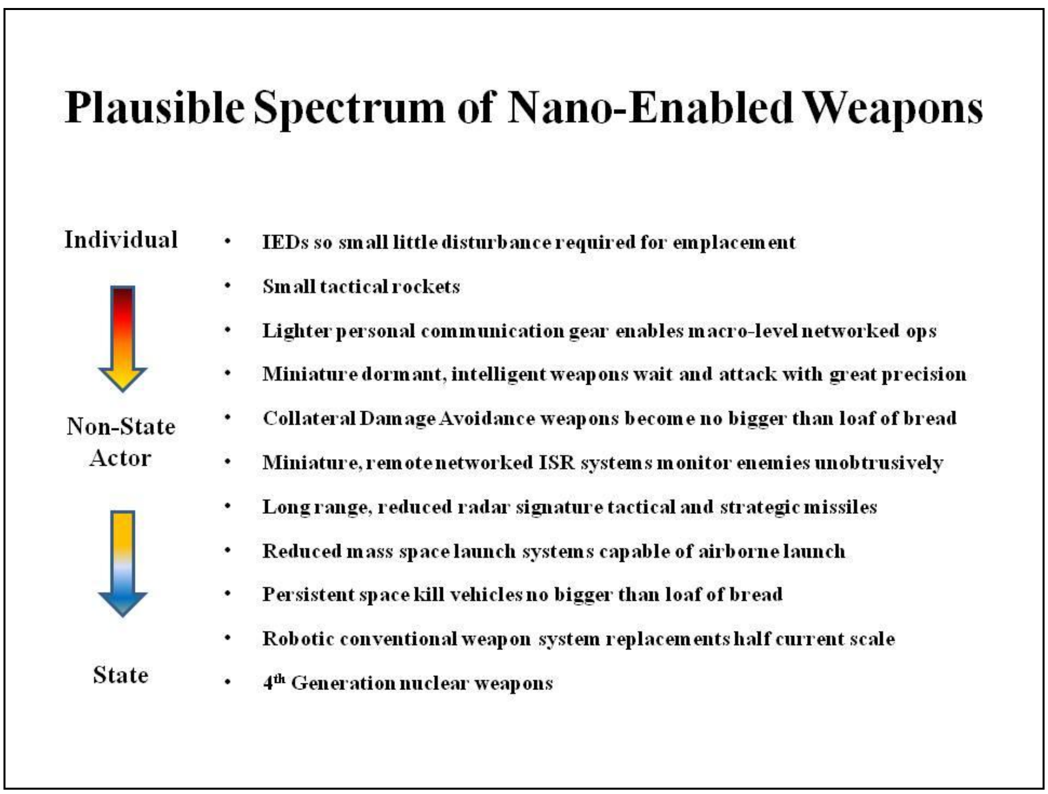

Figure 6: Nano-Enabled Spectrum [77]

A full analysis of nano-energetics' impact on military systems will yield critical vulnerabilities from which deterrent strategies may be developed, though not necessarily accurately predicting the precise applications of the technologies. The first step is identifying who is capable of manufacturing the essential nano-energetic components (as of 2010 these appear to be nano-aluminum, MICs, CNTs and carbon nanowires). Next is determining which systems, though enhanced by nanotechnology, are better but not different. These systems will not affect current deterrence postures. Finally, identifying methodologies for detecting and exploiting nano-enhanced systems must be accomplished to provide credible deterrence.

Transparency will play a large role in deterring nano-enhanced systems. Trace amounts of reactant or oxidizers will be present near nEMs of any size. Industrial laser technology exists to actively detect carbon monoxide and nitrous oxide.[78] This technology will serve as the basis for detecting reactants and oxides associated with nEMs. While the breadth of nEM components make detection technically challenging, micro-cantilevers have been shown to passively detect trace amounts of explosive crystals dependent on the material used in the cantilever.[79] Nanoscale cantilever component design can be exploited in the future to enable detecting a wide array of nEM material. Miniaturized devices enhanced by nano-inspired batteries will have an energy signature (in the radiation spectrum) which will be detectable. New detection equipment will need to identify extremely finite traces or particles per million, flagging specific materials to identify nEMs and nano-inspired battery systems. Though technically challenging, this will provide the strongest form of deterrence by eliminating the chance for successful surprise employment of miniature devices.

Nano-energetics' radical impact on space systems deserves further deliberate thought and investigation. Nano-energetics and nano-enhanced batteries will make space more accessible and the weaponization of space far more achievable. Shrinking rocket requirements coupled with miniature sensors will increase the number of space participants. Affordable, small kinetic kill air-launched missiles are within the realm of the possible. Detecting and deterring space weapon systems will become infinitely more difficult as nanotechnology proliferates. Considerably more deliberation should be given to this threatening possibility in the coming years.

Conclusion

> *History is replete with examples of militaries that failed due to their inability to transform organizations and culture, adopt new operational concepts, or leverage breakthrough technologies…victory comes to those who foresee, recognize and act on changes in the strategic environment.*
>
> General T. Michael Moseley, CSAF 2007[80]

Nanotechnology will radically transform the weapon system paradigm over the next fifty years. By 2035, nano-energetics will yield vast improvements to many traditional weapon systems by shrinking system mass and increasing reliability. Nano-inspired batteries and nEMs will revolutionize space access and miniaturized weapons. A new, lethal weapon system family composed of mini-mines, persistent micro-sensors and micro attack devices will emerge.[81]

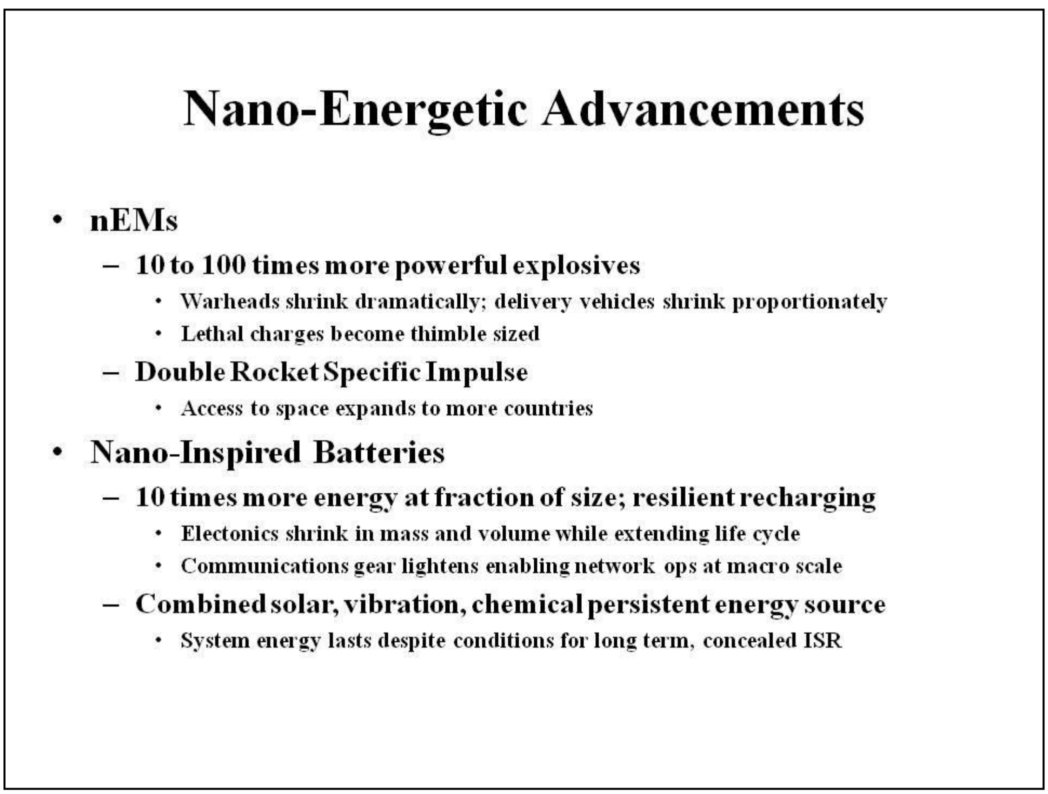

Figure 7: Nano-Energetics Advancements Summary

Nanotechnology is currently proliferating through collaborative scientific endeavors across the hard sciences.[82] Nations, non-state actors, and individuals vie for use of these new technologies for their purposes. No nation is capable of halting nanotechnology advancement. Any nation that attempts to limit development will not capitalize on the nanotech revolution.

The United States will benefit economically and militarily by increasing nanotechnology research and development. The U.S. National Nanotechnology Initiative acknowledges and provides government emphasis on achieving higher quality products benefiting consumers while creating new high-tech jobs.[83] Nano-business expanded five-fold alone from 2006 to 2008 ($32B to $150B), creating 25,000 additional jobs and doubling the number of products.[84] Funding basic research will further the U.S. role as a leader in nano-energetics development.[85] The Department of Defense should publish a nanotech initiative supplement to organize nanotech efforts and to provide overarching guidance for military nanotechnology research. Ensuring transparency of U.S. Department of Defense nanotech capabilities will provide credible, capable, and communicated deterrence as espoused by Professor T.V. Paul.[86] The importance of nanotech to future U.S. economic development is matched by the utility of nanotech exploits to detect and deter nanotech-inspired weapons while fielding cutting-edge nanotechnology across the military spectrum.

Luddites will espouse that radicalized individuals and run-away experiments make nanotech far too dangerous for continued funding. Advocates of the precautionary principle will seek to limit discovery in fear of experimentation byproducts. This is not reasonable cause for minimizing the efforts of the world's technological leader, as it will be far better to be on the leading edge of discovery and understand how to detect, control and counteract nanotech enabled technologies.[87] Furthermore, nanotechnology is not a single field of science that can be addressed or contained.[88] Nanotechnology is the natural extension of the basic scientific disciplines (chemistry, biology and physics). The evolution of scientific research will lead to revolutionary discoveries at the nano-scale with or without U.S. involvement.

Nanotechnology development is in the national security interest of the United States. It will be instrumental to strong national defense beyond 2035. Nanotechnology research will provide radical new systems to deter future threats and detect and defeat them when required.[89] The Department of Defense must have a clear vision of the importance of nanotech research and development and how nanotech will alter future warfighting. Proverbs 29:18 prophetically declares, "When there is no vision, the people perish." If the U.S. military does not adequately prepare for the oncoming nanotechnology revolution it will be vulnerable to devastating lessons learned on tomorrow's battlefields!

ENDNOTES

[1] Mikhail Tukhachevskiy, *New Problems in Warfare*. AMSP Course 1 SAMS Reprint from U.S. Army War College Art of War Colloquium. Carlisle Barracks, Pennsylvania: Army War College, 1983.

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[5] Edward L. Wolf, *Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience*. 2nd Edition. (Weinheim, Germany: Wiley-VCH, 2006), 86.

[6] Prakash, Smita. "Thorium Reactors Integral to Indian Energy Independence." Energy Daily, May 8, 2007. http://www.energy-daily.com/reports/Thorium_Reactors_Integral_To_Indian_Energy_Independence_999.html.

[7] Extensive research was conducted utilizing online web search engines as well as common library search tools (such as ProQuest and EBSCOHOST). Over the 4 month research period no less than 100 technical papers such as NanoLetters were reviewed. Of these, approximately half were written as collaborative efforts by scientists representing universities, corporations and governmental research institutes from different countries.

[8] National Research Council, *A Matter of Size: Triennial Review of the National NanoTechnology Initiative*. Committee to Review the National NanoTechnology Initiative, Washington DC: The National Academies Press, 2006, p. 5. Analysis of the annual number of nanotechnology papers and patents awarded indicate significant worldwide growth in research and development and related intellectual property sharing. Journal papers originating within the U.S. accounted for approximately 30% of the total in 2004.

[9] John P. Geis, II. "The Age of Surprise: Implications of Exponential Technological Change on Air Force Strategy" (2010 AETC Symposium: Developing America's Airmen Today…for Tomorrow, San Antonio, Texas,14 January 2010).

[10] Richard P. Appelbaum and Rachel A. Parker. "China's Bid to Become a Global Nanotech Leader: Advancing Nanotechnology through State-led Programs and International Collaborations." Science and Public Policy, June 2008. http://www.allacademic.com//meta/p_mla_apa_research_citation/2/4/2/1/7/pages242170/p242170-1.php. An example of the nanotechnology race between nations is China's recent decision to feature nanotechnology research and development prominently in its 2011 budget and beyond. China will invest 2.5 percent of its gross domestic product beginning in 2011 on nanotech research as it believes that 15 percent of all goods traded internationally by 2015 will rely on nanotech. This will compliment China's commitment to sending scientist abroad for nanotech collaboration which in turn increases nanotech expertise for Chinese manufacturing. Appelbaum and Parker assert that China is planning to leap-frog other countries thru collaboration and outspending.

[11] Richard Mumford, "International Report: Anglo-China Nanotechnology Collaboration." Microwave Journal, August 2009.

http://www.mwjournal.com/journal/issues.asp?HH_ID=AR_7932&title=Anglo-China Nanotechnology Collaboration. One prescient example is how the United Kingdom and China are collaborating on advanced nano-computing and the basis required for "spintronics." The UK Engineering and Science Research Council and the National Science Foundation of China have teamed to provide 430,000 British Pounds for ultra-small scale silicon semiconductors for use in nanotech devices, namely computer spintronics. The project, funded for 3 years, exchanges scientists to use both countries expertise as well as collaboration from the Dutch university at Utrecht.

[12] Vincent T. Jovene, "Next Generation Nanotechnology Assembly Fabrication Methods." Occasional Paper No. 64. Center for Strategy and Technology, Air War College. Maxwell Air Force Base, AL: Air University Press, 2008, p. 19-20.

[13] Saurav Dutta, Raef Lawson and David Marcinko. "How the NanoTechnology Revolution will Affect Cost Management." The Journal of Corporate Accounting and Finance, March-April 2006. Dutta, Lawson and Marcinko carefully explain the differences in the margins when manufacturing nanotechnology products. Though the manufacturing plant can be quite costly, once in production the cash inflow greatly outweighs expenditures. Hence, cash outlays must be available early in development and profit margins grow rapidly in production phases.

[14] Roger Allen, "Nano-Technology: The Next Revolution to Redefine Electronics." *Electronic Design*, 26 May 2003.

[15] Carole Rossi, Kaili Zhang, Daniel Esteve, Pierre Alphonse, Philippe Tailhades and Constantin Vahlas. "Nano-Energetic Materials for MEMS: A Review." *Journal of Microelectromechanical Systems*, Vol 16, No. 4, August 2007. Researchers are filling the pores with metastable intermolecular compounds; the pores open on impact and the energetic compounds react.

[16] Carole Rossi, Kaili Zhang, Daniel Esteve, Pierre Alphonse, Philippe Tailhades and Constantin Vahlas. "Nano-Energetic Materials for MEMS: A Review." *Journal of Microelectromechanical Systems*, Vol 16, No. 4, August 2007.

[17] Ben Ames. "Nano-Technology Delivers Military Power." *Military and Aerospace Electronics*, May 2005.

[18] Zh Zhao, X.J. Li, H.H. Yan and D.H. Liu. "Explosive Compaction of Nano-Alumina Particle Reinforced Copper Alloy. *Combustion, Explosion, and Shock Waves*, Vol 44, 2008.

[19] Richard Booker and Boysen, Earl. *Nanotechnology for Dummies.* (New Jersey: Wiley Publishing, Inc., 2005) 76-78.

[20] M. Al-Haik, M.Y. Hussaini and H. Garmestani. "Adhesion Energy in Carbon Nanotube-Polyethelene Composite: Effect of Chirality." *Journal of Applied Physics* 97, 2005.

[21] Dereje Seifu and Shashi Karna. "High Yield Magnetic Nanoparticles Filled Multiwalled Carbon Nanotubes using Pulsed Laser Deposition." 26th Army Science Conference, December 2008. http://www.asc2008.com/manuscripts/M/MP-01.pdf.

[22] Wuming Zhu, Arne Rosen and Kim Bolton. "Changes in Single-Walled Carbon Nanotube Chirality during Growth and Regrowth." *The Journal of Chemical Physics*, 128, 27 March 2008.

[23] Victor E. Borisenko and Stefano Ossicini. *What is What in the Nanoworld: A Handbook on Nanoscience and Nanotechnology*. (Weimheim, Germany: Wiley-VCH, 2004),40.

[24] Ali Afzali-Ardakani, Phaedon Avouris, Jia Chen, Christian Klinke, Christopher Murray, and

Dmitri Talapin. "Chemical Doping of Nano-Components." United States Patent #7582534, September 1, 2009. http://www.freepatentsonline.com/7582534.html. Doping in this context refers to introducing individual or multiple atoms of specific elements to achieve different characteristics in the CNT. The non-carbon elements bring some properties themselves but more importantly can be used to alter the covalent bonds of an individual CNT or between multiple CNTs to produce desired structural building blocks. Manufacturers will use doped CNTs to achieve specific characteristics in everything from composite structures to explosive compounds.

[25] , Robert V. Gates, "What's So Important About Energetics? Everything!" *U.S. Naval Institute Proceedings*, Vol. 135, April 2009.

[26] The scientific community uses the abbreviation nEM for nano-energetic materials to prevent confusion with nano-electro mechanical systems (NEMS).

[27] Extensive research is being done on one class of nEMs, nanothermites (synonymous with superthermites). MIC are thermites commonly on the nano-scale; however, some researchers use MIC above the nano-scale as defined by the NNI and used in this paper.

[28] Kaili Zhang, Carole Rossi and G.A. Ardila Rodriguez. "Development of a Nano-Al/CuO Based Energetic Material on Silicon Substrate." *Applied Physics Letters* No. 91, 14 September 2007. Mass transport in this context refers to minimizing the distance between reactants and oxidizer by positioning them precisely at the nano-scale. Preventing premature oxidation and degradation of the material is vital to success. Larger organic molecules incur less instantaneous transfer due to the relative distance between reactants and oxidizers. Solid nEMs present the opportunity for precise proximity with very little degradation.

[29] Superthermites are a faster ignition source resulting in a quicker flash and bang.

[30] John Gartner, "Military Reloads with Nanotech." *Technology Review, An MIT Enterprise*, January 21, 2005. http://www.technologyreview.com/computing/14105/page1/

[31] Guangcheng Yang, Fude Nie, Jinshan Li, Qiuxia Guo and Zhiqiang Qiao. "Preparation and Characterization of Nano-NTO Explosive." *Journal of Energetic Materials*, 25, 2007.

[32] Kaili Zhang, Carole Rossi and G.A. Ardila Rodriguez. "Development of a Nano-Al/CuO Based Energetic Material on Silicon Substrate." *Applied Physics Letters* No. 91, 14 September 2007.

[33] A. Prakash, A.V. McCormick and M.R. Zachariah. "Thermo-Kinetic Study of Core-Shell Nano-Thermites." *Shock Compression of Condensed Matter*, American Institute of Physics, 2005.

[34] A.V. Utkin, G.I. Kanel, A.A. Bogach and S.V. Razorenov. "Macro-Kinetics of the Energy Release in High Explosives Containing Nano-Size Boron Particles." *Shock Compression of Condensed Matter*, American Institute of Physics, 1999.

[35] Oleg Vasylkiv, Yoshio Sakka and Valeriy V. Skorokhod. "Nano-Blast Synthesis of Nano-Size CeO2-Gd2O3 Powders." *Journal of American Ceramic Society*, No. 89, 2006.

[36] John Gartner, "Military Reloads with Nanotech." *Technology Review, An MIT Enterprise*, January 21, 2005. http://www.technologyreview.com/computing/14105/page1/.

[37] Ibid.

[38] W.Gutkowski and T.A. Kowalewski. *Mechanics of the 21st Century*. (Netherlands: Springer, 2005), 379. "We discuss a range of issues, theoretical, computational and experimental, required to scale the size of explosive systems downwards by a factor of one hundred to

one thousand, applications and prospects for a ubiquitous new technology."

[39] A.E.Van der Heijden, R.H.Bouma, E.P. Carton, M. Martinez Pacheco, B. Meuken, R. Webb and J.F. Zevenbergen. "Processing, Application and Characterization of (Ultra)Fine and Nanometric Materials in Energetic Compositions." *Shock Compression of Condensed Matter*, American Institute of Physics, 2005.

[40] Jurgen Altmann. *Military Nanotechnology*. New York: Routledge, 2006, 106.

[41] B.C. Tappan, S.F. Son and D.S. Moore. "Nano-Aluminum Reaction with Nitrogen in the Burn Front of Oxygen-Free Energetic Materials." *Shock Compression of Condensed Matter*, American Institute of Physics, 2005.

[42] L.T. De Luca, L. Galfetti, F. Severini, L. Meda, G. Marra, A.B. Vorozhtsov, V.S. Sedoi and V.A. Babuk. "Burning of Nano-Aluminized Composite Rocket Propellants." *Combustion, Explosion, and Shock Waves*, Vol. 41, 2005.

[43] Jeremy Hsu. "New Rocket Fuel Mixes Ice and Metal." Space.com, October 21, 2009. http://www.space.com/businesstechnology/091021-tw-alice-rocket.html.

[44] John Gartner, "Military Reloads with Nanotech."

[45] John W. Cole, Isaac F. Silvera and John P. Foote. "Conceptual Launch Vehicles Using Metallic Hydrogen Propellant." Space Technology and Applications International Forum 2008. *American Institute of Physics Conference Proceedings*, Vol. 969, January 2008. Cole *et al* demonstrate the impact of solid metallic hydrogen (20 times the specific energy of hydrogen/oxygen used in the space shuttle) in vastly changing the rocket mass paradigm per given payload. Metallic hydrogen does not exist on earth-yet. Nano research will likely provide the methodology for achieving metallic forms of hydrogen.

[46] "The Rocket." MIT Dept. of Aeronautics and Astronautics Educational Webpage, May 1996. http://web.mit.edu/16.00/www/aec/rocket.html, February 17, 2010.

[47] I_{sp} equals total impulse (force of the rocket engine) divided by weight of the propellant. The equation reacts to energetic composition of the propellant or changing rocket engine efficiency. Both can be affected by nano materials that waste less fuel during a cleaner, more instantaneous ignition and sustained burn. Mathematically doubling I_{sp} is equivalent to cutting propellant weight in half. This changes the nominal 0.8 mass fraction to 0.66 whereby propellant mass decreases 50 percent (from 80 to 40 units) while overall mass decreases by 40 percent (from 100 to 60 units).

[48] Jurgen Altmann. *Military Nanotechnology*. (New York: Routledge, 2006), 108.

[49] Kevin Bullis, "Powerful Batteries That Assemble Themselves." *Technology Review, An MIT Enterprise*, September 28, 2006. http://www.technologyreview.com/read_article.aspx?id=17553.

[50] Carole Rossi, Kaili Zhang, Daniel Esteve, Pierre Alphonse, Philippe Tailhades and Constantin Vahlas. "Nano-Energetic Materials for MEMS: A Review." *Journal of Microelectromechanical Systems*, Vol 16, No. 4, August 2007.

[51] Ibid.

[52] Edward L. Wolf, *Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience.* 2nd Edition. (Weinheim, Germany: Wiley-VCH, 2006), 138. Researchers have shown that electrons can pass through the micrometer length of CNTs with zero scattering and zero heat dissipation.

[53] Kevin Bullis. "The Ultra Battery." *Technology Review, An MIT Enterprise*, February 13, 2006. http://www.technologyreview.com/article/16569/.

[54] Victor E. Borisenko and Stefano Ossicini. *What is What in the Nanoworld: A Handbook on Nanoscience and Nanotechnology*. (Weimheim, Germany: Wiley-VCH, 2004), 236. CNTs, nanowires, and quantum dots are useful in that they can be used to confine the direction of electron movement. They significantly enhance the design of new materials that achieves superconductivity without the requirement to greatly cool the structure.

[55] Katherine Bourzac, "More Energy in Batteries." *Technology Review, An MIT Enterprise*, November 6, 2009. http://www.technologyreview.com/energy/23893/ .

[56] Tyler Hamilton, "Battery Breakthrough?" *Technology Review, An MIT Enterprise*, January 22, 2007. http://www.technologyreview.com/biztech/18086/. They claim a specific energy of about 280 watt hours per kilogram, compared with around 120 watt hours per kilogram for lithium-ion and 32 watt hours per kilogram for lead-acid gel batteries. "It's really tuned [scalable] to the electronics we attach to it," explains EESTors' CEO, "We can go all the way down from pacemakers to locomotives and direct-energy weapons."

[57] Katherine Bourzac, "A Hybrid Nano-Energy Harvester." *Technology Review, An MIT Enterprise*, April 9, 2009. http://www.technologyreview.com/energy/22410/. The nano-generator is comprised of nanowires that generate current when vibrated on a substrate.

[58] Mark Avrum Gubrud, "Nanotechnology and International Security." November 8, 1997. http://www.foresight.org/Conferences/MNT05/Papers/Gubrud/ .

[59] Katherine Bourzac, "More Energy in Batteries." *Technology Review, An MIT Enterprise*, November 6, 2009. http://www.technologyreview.com/energy/23893/

[60] Jurgen Altmann. *Military Nanotechnology*. (New York: Routledge, 2006), 106.

[61] Brian Jenkins. "Redefining the Enemy: The World Has Changed, but Our Mindset Has Not." *Rand Review*, Vol. 28, No. 1, Spring 2004, 135.

[62] President George W. Bush,(Remarks at the U.S. Naval Academy Commencement. Annapolis Maryland: Mary 25, 2001).

[63] Reflects per unit cost after research and development. Does not reflect system upkeep costs nor is it intended to compare system capabilities or military utility. The comparison shows the revolutionary impact of inexpensive batteries and nEM on weapon systems.

[64] "The Many Uses of Explosives." The World of Explosives Webpage, 2005. http://www.explosives.org/Uses.htm.

[65] Executive Office of the President of The United States of America. *The National Nanotechnology Initiative Strategic Plan*, (Washington DC: December 2004),i. The expressed goals of the NNI are to develop world-class nanotechnologies, facilitate their transfer into peaceful commercial products (creating jobs), develop a skilled workforce and tools to advance manufacture, all while ensuring responsible control of research and development of critical nanotechnologies.

[66] House. *National Nanotechnology Initiative Amendments Act of 2008*. 110th Congress, June 4, 2008, p. 17. The NNI Amendment Act of 2008 directs government agencies supporting nanotechnology research facilities to publicize their availability and to provide procedures for their use in order to facilitate technology transfer into the commercial sector. The economic impact is anticipated to outweigh technology risks.

[67] Linda Willliams, and Wade Adams. *Nanotechnology Demystified*. (New York: McGraw-Hill, 2007), p. 228. As an example of nanotechnology impact on big business, fifty percent of Dow Jones Industrial Average companies as of 2006 either made or were working on

nano-related products. By 2010 this market had grown to over 1000 products produced by 24 nations. For more information see Elizabeth Corley, "Nanotechnology Information Gap Widening." *Arizona State University News*, January 12, 2010. http://asunews.asu.edu/20100111_nanotechreport.

[68] Daniel Ratner, and Mark Ratner. *Nanotechnology and Homeland Security*. (New Jersey: Prentice Hall, 2004), 121.

[69] National Research Council. *A Matter of Size: Triennial Review of the National NanoTechnology Initiative*. Committee to Review the National NanoTechnology Initiative, (Washington DC: The National Academies Press, 2006), 1-12. The Triennial Review of the NNI eloquently spells out the benefits of funding and fostering nano research as well as the pitfalls of failing to support responsible research in its executive summary. The analysis is based on economic impact, access to relevant technology, ensuring responsible development and understanding defense related capabilities.

[70] Mark Avrum Gubrud. "Nanotechnology and International Security." November 8, 1997.

[71] Professor Gubrud asserts that current nuclear weapon stockpiles will be monitored by nano-enable miniature sensors incorporating nEMs. These sensors would be no larger than bugs, mimicking nature to avoid detection. They would destroy the nuclear weapon's integrity by detonating themselves on the weapon before its employment. His concept is difficult to conceive having utility against submarine sea-launched missiles.

[72] Mark Avrum Gubrud. "Nanotechnology and International Security." November 8, 1997. This seemingly contradicts his assertion that nuclear weapons would become obsolete; however, Gubrud distinguishes between current nuclear weapons and a new generation of nuclear weapons that would be at a much smaller scale. The fissile material may be the same, but nano-energetics would provide new detonators and additives enabling nuclear reactions and hence explosives at a miniature scale.

[73] Robert V. Gates. "What's So Important About Energetics? Everything!"

[74] Linda Willliams, and Wade Adams. *Nanotechnology Demystified*. (New York: McGraw-Hill, 2007), p. 155. For example, the Department of Defense is currently using nano-coatings to protect weapon system structures and surfaces from degradation from the elements. This is focused on decreasing the $10B annual cost to repaint and repair weapon systems.

[75] John P. Geis II. The Age of Surprise: Implications of Exponential Technological Change on Air Force Strategy. Geis, John P. II, Christopher J. Kinnan, Ted Hailes, Harry A. Foster and David Blanks. "*Blue Horizons II: Future Capabilities and Technologies for the Air Force in 2030*." (Maxwell Air Force Base, Alabama: Air University Press, July 2009). These two report empirically that the current Department of Defense acquisition system is insufficiently fast to keep pace with future technological development.

[76] Spiral development is the Department of Defense practice of fielding a weapon system while continuing its development. Hardware and software upgrades are routinely included in progressive increments thereby spreading the cost over time.

[77] The spectrum demonstrates that weapon systems from simple explosive charges to highly complex space and nuclear weapon systems will be affected by nEMs and nano-inspired batteries.

[78] V.L. Kasyutich, R.J. Holdsworth and P.A. Martin. "Mid-Infrared Laser Absorption Spectrometers Based upon All-Diode Laser Difference Frequency Generation and a

Room Temperature Quantum Cascade Laser for the Detection of CO, N2O and NO." *Applied Physics B: Lasers and Optics*, 2008.

[79] Larry Senesac, and Thomas Thundat. "NanoSensors for Trace Explosive Detection." *Materials Today*, Vol 11, No. 3, March 2008. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6X1J-4RV7SXC-K&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1133444248&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=d98198774a7e62a892c3a32da6c97df6.

[80] General T. Michael Moseley "CSAF White Paper: The Nation's Guardians, America's 21st Century Air Force," 29 December 2007, p. 2.

[81] Michael Lindsay, Air Force Research Laboratory Energetic Materials Branch Research Chemist. Phone Interview at United States Air Force Academy: January 14, 2010. Professor Lindsay asserts that nEMs will provide structure and munition in one material that will enable a new extremely small lethal UAV family.

[82] "Advances in Nanomaterials." *American Ceramic Society Bulletin* Vol. 85, No. 8, 2006. For example, Frontiers, the European nanotechnology network, was established in 2004 and combines facilities, funding, and 12 nanotechnology institutes' expertise across Europe and over 200 worldwide research and development scientists.

[83] National Nanotechnology Initiative. www.nano.gov.

[84] Jim Dawson. "Nanotechnology in Manufacturing is the Focus of Industrial Physics Forum." *Physics Today* Vol. 60, Issue 1, January 2007.

[85] Shanthi Subramanian, Terry Tiegs and Santosh Limaye. "Nanoporous Silicon Based Energetic Materials." 26th Army Science Conference, December 2008. http://www.asc2008.com/manuscripts/M/MP-08.pdf. "Possible applications for these materials [nEMs] include use in environmentally clean primers and detonators, chem/bio agent neutralization, improved rocket propellants, IR flares/decoys, high temperature stable, non-detonable gas generators and thermal batteries." This is due to their insensitivity and tailorable structure which will benefit the many civilian uses as well as military purposes.

[86] Paul, T.V., Patrick Morgan, and James Wirtz. *Complex Deterrence: Strategy in the Global Age.* Chicago: University of Chicago Press, 2009, p. 2.

[87] , David H Guston. "Innovation Policy: Not Just a Jumbo Shrimp." *Nature*, Vol. 454, August 21, 2008. Guston declares, "Global society needs much of what knowledge-based innovation has to offer. Anticipatory governance is a necessary exercise. It defrays the inherent contradictions of innovation policy, while ensuring that public values and foresight accompany scientific practice, keeping the revolution from turning unproductively against itself and against us."

[88] Stephen Wood, Alison Geldart and Richard Jones. "Crystallizing the Nanotechnology Debate." *Technology Analysis & Strategic Management*, Vol. 20, No. 1, January 2008. In the nanotech debate's journey from radical beginnings to the present, Wood *et. al.* conclude that all too often nanotechnology is treated as homogeneous, either connected in some way with the Drexlerian vision of uncontrollable nano gray-goo or an ill-defined application of science at the nano level.

[89] Sara M.C.Vieira, Paul Beecher, Ibraheem Haneef, Florin Udrea, William I. Milne, Manoj A.G. Namboothiry, David L. Carroll, Jonghyurk Park and Sunglyul Maeng. "Use of

Nanocomposites to Increase Electrical "Gain" in Chemical Sensors." *Applied Physics Letters* No. 91, November 14, 2007. A good example of radical new detection capabilities is the gas doping of CNTs combined with CMOS (complimentary metal-oxide-semiconductor technology) which resulted in gas sensing devices with very low power consumption and incredible sensitivity detecting singular gas particles per billion!

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