Out of the Box and Into the Future:

A National Security Forecast

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The Potomac Institute for Policy Studies is an independent, 501(c)(3) not-for-profit public policy research institute that provides nonpartisan analysis of technology and technology policy to leaders in government, business, and academia. As the logo suggests, the Institute's work reflects the summation of technology's effects on business and government. With a reputation for fierce objectivity, the Institute has conducted studies on a wide range of technology policy topics including defense acquisition reform, dual use technology, biological terrorism, cyber-terrorism, and space commercialization.

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PREFACE

The Potomac Institute for Policy Studies (the Institute) is proud to offer this analytical report of information and perspectives collected during the *Out of the Box and Into the Future Project* (the "Project"). It is important to note that the impetus for this Project came from Congress, and in particular, the *Out of the Box and Into the Future* conference and associated activities were conducted at the request of Senators Joseph Lieberman, Pat Roberts, and Jeff Bingaman; and Congressmen Curt Weldon and Rob Andrews. The letters from Congress initiating the Project are in Appendix A.

The Project culminated in a conference in June 2000, attended by world-class scientists and warfighters who spoke about their areas of expertise. Their words, as faithfully transcribed as possible, can be read directly in the proceedings. Our mission, in the following pages, was to integrate these perceptions and information across the many scientific disciplines and warfighting aspects that were addressed.

We hope this work furthers the dialogue among warfighters and scientists. We thank the contributors, those who spoke and wrote for the events, and those who encouraged us with words and sponsorship. The Institute would like to gratefully acknowledge the support and sponsorship of: Air Force Office of Scientific Research, Department of the Army, Defense Advanced Project Research Agency, National Intelligence Council, National Science Foundation, Office of Naval Research, U.S. Joint Forces Command, IBM Corporation, Armed Forces Journal International, American Association of Engineering Societies, and the Coalition for National Security Research. But, in the end, this document does not necessarily reflect the opinions of those contributors. It is the sole responsibility of the Institute.

The Institute is eager to receive any comments you may have on this Project or its output. Any questions or contributions may be sent via email through our website, www.potomacinstitute.org.

> Throughout the Project, we have set out to predict some of the things that are likely to happen over a period of twenty-five years. Perhaps this is a "fool's mission" but it must be attempted – often and from various perspectives. It is important to gain an understanding of the forces of change and the probable effects of those forces without becoming gulled into believing in "one reality."
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> Our trepidation is dampened by Peter Schwartz's admonition, "It is simply not possible to predict the future with certainty. An old Arab proverb says that, 'He who predicts the future lies even if he tells the truth.' "[1]

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[1] Peter Schwartz, *The Art of the Long View* (New York: Currency Doubleday, 1991), p. 6.

EXECUTIVE SUMMARY

This summary presents selected thoughts developed during the Out of the Box and Into the Future (the "Project"). The Project examined some of the impacts of six major areas of science and technology on military operations for the far-future (2025). Clearly, we could not comprehensively cover such a set of complex and diverse subjects in one project. Our aim was more modest, to bring together and document the perspectives of important contributors in each area of interest. This process should continue and there are plans to do that.

BACKGROUND

The incredible pace of scientific and technological change, combined with the uncertainty of future threats, makes forecasting the nature of far-future military operations both difficult and crucial as we enter the 21st century. Ensuring the United States' science and technology (S&T) superiority is a necessary step. But, we must also make certain that far-future military operations exploit expected advancements in S&T. These are profound undertakings, particularly when the path to progress is often strewn with organizational structures, priorities, and funding distributions that have changed little since the Cold War era. Although recently, renewed interest in concepts of jointness, combined with evolving experimentation techniques, have offered some important ways to think about and exercise the confluence of technology and military operations. There is also an increased tempo in the military's efforts to think through the implications of new technologies and global environments and threats. Over the past ten years, global changes have been legion, as will be discussed in Chapter II of this report.

We are experiencing a time of scientific discovery and application that is unrivalled in history. The influence of these changes on military affairs is already profound and will surely grow during the next 25 years. More importantly, their influence on the civil sector is even more profound and the boundaries between the military and civil sectors are becoming increasingly blurred. As a result, considerations of military S&T and operations are no longer confined to defense, but are affected by and affect society as a whole.

For many areas of science unfolding change is so esoteric that only a few experts understand its possible directions. Similarly, the warfighter faces an increasingly complex far-future landscape, with ill-defined enemy operations and new allied and threat weapons technologies. Yet over the next quarter-century, even as military doctrine, threats, the global environment, and S&T change and exert mutual influences on one another, DoD must iteratively develop new ways to shape its operations and systems to meet the challenges of new and diverse missions. It must also increasingly involve the rest of government and the private sector in these decisions.

ORGANIZATION OF THIS REPORT

Overarching conclusions and recommendations developed during the "Out of the Box and Into the Future" Project (the "Project") are summarized in the next few pages. The first chapter describes the Project, its output, and how it contributed to the report. This chapter may be skipped if the reader is not interested in the process used. Chapter II offers a discussion of the global political environment and threats we are likely to face in the coming 25 years. Military operations in the first quarter-century are the subject of Chapter III, which forecasts the impacts of advancements in six areas of science and technology: energy, advanced materials, nanotechnology, human factors and neuroscience, biomedicine, and information and knowledge. The fourth chapter provides some deeper observations about these six areas. In Chapter V we discuss some of the problems facing the Department of Defense (DoD) in acquiring these technologies. This is followed, in the final chapter, by suggested next steps to be taken.

SELECTED CONCLUSIONS AND RECOMMENDATIONS

As discussed later in Chapter I, the Project drew on the results of fifteen selected futures studies, several articles and papers, a seminar series conducted by the Institute, and a two-day conference. Two classes of conclusions and recommendations emerged. The first stems from large trends and issues that will have a profound effect across the globe, while the second reflects subsidiary issues and trends that mainly impact the military.

I. Conclusions and Recommendations Concerning Large Trends and Issues.

Over the next quarter century, several trends in political and military environments, and in science and technology are likely to produce profound changes in the national and international arena. All of these trends have two characteristics in common. The first is that their effects, whether harmful or beneficial, will be extremely powerful. The second common characteristic is that they require national attention focused in a unique way if we are to positively influence their impacts. Like the problems of drugs and international crime, no single government department or agency can hope to address them successfully – no private sector organization has sufficient power or reach. In fact, they must ultimately be subject to international collaboration if we are to gain their full benefits or mitigate their potential harm. In the meantime, the U.S. should set the example, by initiating cross-cutting national programs to engage the public and private sectors in building and implementing holistic strategies and solutions. The nature of these strategies and solutions are discussed briefly under "Recommendations."

The political landscape will continue to feel the effects of Post Cold War phenomena, but these times are beginning to assert their own character, and cannot simply be judged in relation to the Cold War era. A mix of economic, social, political, and military pressures, as well as scientific discoveries that uniquely belong to the twenty-first century are emerging, molding a world that will demand our innovation and active engagement. Some characteristics of this new world are:

A. **Conflicts will continue to arise across the globe, and U.S. interests and sympathies will lead to a broad spectrum of involvement, from exerting diplomatic influence to engaging in various forms of armed conflict.**

B. **The nature of these conflicts will be extremely diverse, and may include terrorism; possible attacks on the homeland, humanitarian crises, limited war, and war with a peer competitor.** While DoD will assume greater responsibilities for homeland defense and counter-terrorism, successful response to changing environments, threats, and technologies will demand continued efforts of our government to influence the international community. It will also demand the adoption of a consistent, fast, and effective cross-cutting interagency response that must be initiated considerably before military intervention becomes compelling. Should armed conflict occur, it would require joint and coalition-oriented commands. Some features of these situations are offered below.

   1. *Characteristically, we will have less time to prepare for situation-specific peaceful or military interventions that can escalate quickly.* This will demand much better interagency approaches to the transition from diplomacy to armed conflict.

   2. *Infrastructures will be greatly improved through new technologies, but as our dependence on these technologies increases, we will be increasingly threatened by their intentional or inadvertent disruption.*

   3. *Urban issues and operations will become more common and will require new civil and military strategies, as well as special technologies.*

C. **Weapons technologies, often developed for our military use will be proliferated more quickly to adversaries, and even terrorists.** Weapons of Mass Destruction (WMD) capabilities will be acquired by more nations, sub-national groups, and individuals, and will likely be used. These capabilities will include nuclear munitions and biological and chemical agents. The most disturbing potential for global catastrophe lies in the deployment of bioagents, incorporating airborne contagious pathogens. We will face less powerful weapons, often developed in this country, such as remote, precision munitions that are effective, accurate, easy to use, and inexpensive – attractive features for the asymmetrical warrior.

D. **Advancements in S&T will bring marvelous benefits, frightening consequences, and ever-greater safety and ethical challenges.** Along with exciting potential for good, many areas of S&T could present catastrophic effects triggered either intentionally or inadvertently. Man acquired the ability to annihilate life over much of the planet with the invention of thermonuclear devices during the mid-1960s. During the first quarter of this century, nuclear concerns will grow and we may well add three more paths to Armageddon.

   1. *Research in biology (especially genetics) will produce impressive solutions for diagnosis and treatment of diseases.* Biomedicine is likely to produce the most

disruptive effects on society (and the military).[2] Impressive strides being made in genetics, neuroscience and other medical science will lead to major breakthroughs in treating health and injury in civilian life and on the battlefield. In the near term, we shall see the extensive use of telemedicine, noninvasive tools for diagnosis and treatment, and automated and electronic records systems. Within the next quarter century, pharmacogenomics may produce "Swiss army knife" treatment packets with capabilities against many of the injuries and diseases faced by combatants, or "spray-on" clothing that protects injuries and dispenses drugs, when needed. The elimination of many genetic tendencies toward tragic and costly illness may well be available during the next twenty or so years. Eventually, the confluence of nano-technology and biology could catapult medicine into a new era. *On the other hand, the proliferation of gene manipulation techniques can easily lead to catastrophic consequences we cannot begin to predict at this point.* Results may include specially designed pathogens for terrorist use with great resilience and airborne contagion, perhaps even targeting specific ethnic groups. Of equal concern are accidental catastrophes in a future where teenagers could easily manipulate genetic materials using simple equipment, perhaps to create an exotic pet.

2. *If nanotechnology lives up to its promises (and the jury is still out) biomedical and electronic applications will likely have an overwhelming impact on society and the military.*[3] Nanotechnology may produce materials with exquisitely tailored properties that are orders of magnitude better than today's (e.g., strength two orders of magnitude greater than that of steel at one-sixth the mass), computers that can hold the entire contents of the Library of Congress within the space of a sugar cube, and bio-medical nano-machines that perform surgery or chemotherapy. *But, the dangers of nanotechnololgy must be heeded.* The abilities of these molecular constructions to perform new and profound functions, combined with a possible ability to self-replicate and to merge with information technology and biology have caused many to fear their introduction.[4]

3. *Weather manipulation is another growing potential for global disaster because of man's increasing impact on the earth's atmosphere.* We continue to dramatically change the composition of our air. Aside from evidence provided by

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[2] In this context, "disruptive" is used to describe S&T applications that produce dramatically good or bad changes in the way people do things.

[3] "The implications of nanotechnology are particularly revolutionary given that such technologies will operate at the intersection of information technologies and biotechnologies. This merging of technologies will produce smaller, more stable, cheaper circuitry that can be embedded and *functionally interconnected*, into practically anything – including organic life forms." U.S. Commission on National Security/21st Century (Hart-Rudman Commission), *New World Coming: American Security in the 21st Century Supporting Research and Analysis*, September 15, 1999, p. 8.

[4] Bill Joy's recent warning against the potential harm of combining nanotechnology with biology and robotics is a good example of this concern. See Bill Joy, "Why the future doesn't need us," *Wired*, April 2000.

improving, but still crude models and empirical data on growing weather variations, we do not know how extreme the consequences of these changes might be. Moreover, long-standing research projects on how to intentionally manipulate local weather, which will certainly cause significant global effects, may lead nations to change weather patterns to their advantage – and to the detriment of their neighbors. Although manipulation of weather may not be successful over the next 25 years, there is little chance that we will significantly reduce the rates of consumption-generated atmospheric changes, which may well manifest in serious global problems. One possible scenario is based on the world's dependence on high agricultural productivity and efficient supply lines. It was suggested during the conference that in the event of a cold wave or similar global weather catastrophe, much of civilization could be ruined over the next decade in a series of wars over the remaining food, exacerbated by an increasingly monolithic investment in hybrid, perhaps genetically altered, crops.[5]

4. Smaller, but still extremely significant, potential for change will emerge from other current research. *For example, neuroscience will promote an understanding of the brain, which may lead to the development of neurological interventions*, such as precision drugs and feedback devices, which can temporarily increase specific mental and physical capabilities, or which can affect emotional reaction to stimuli. This same understanding will eventually make training and education more effective by orders of magnitude. Society has a large stake in these applications, but serious ethical and policy issues must first be resolved. Military applications will be extremely broad, ranging from making warfighters smarter, braver, or stronger during combat, to destroying an enemy's will to fight or a population's will to resist.

Recommendations. As stated earlier, each of these issues share a common feature – all must be addressed from a broad national platform. These are such serious national security issues they deserve the incorporation of skills and insights from across many government agencies, academia, and the private sector. We do not do this well, as illustrated by our attempts to assemble combined federal and local solutions to terrorism and the war on drugs. Moreover, when faced with diminishing budgets, government departments classically focus their efforts by selecting a small number of high-priority items that directly reflect their individual missions, ignoring the remainder. [6] Most often the critical trends discussed above are on everyone's "remainder" list and, because they are not the responsibility of any one organization, fail to make the "top ten" issues that receive attention.

A viable approach may be to initiate a national organizational structure that can operate in a setting of shared responsibilities to address problems that may not appear

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[5] See Dr. William H. Calvin's presentation in the *Out of the Box and Into the Future Conference Proceedings*.

[6] Examples of this focusing mechanism are the DoD's Advanced Concept Technology Demonstrations (ACTD) and the Navy's Future Naval Capabilities (FNC).

on the critical path of any one agency -- perhaps to be conducted under the leadership of the National Security Council. It could also feature a set of Proactive Red Teams, along with an experimentation process to develop and exercise various approaches. This structure would allow the U.S. to *collaboratively* assess and build upon these trends, and to continuously test our ability to handle the spectrum of futures that they may present. Specifically, the U.S. should:

1: *Prepare for the full spectrum of involvement to mitigate homeland attack, terrorism, humanitarian crisis, war, or harmful effects of S&T. This calls for careful prioritization of our limited resources and time to concentrate on the most likely scenarios, without neglecting those that are less likely. For the entire government, it necessitates a holistic strategy conducted with the efficient involvement of agencies across federal and local levels and the participation of the private sector. For the DoD, it adds even more emphasis to the need to conduct operations in a joint and coalition environment. Special attention should be paid to the likelihood that we will face our own technologies across the battlespace.*

2: *Examine increasingly difficult and common urban issues and develop operations to address them.*

3: *Establish collaboration with DoD, National Science Foundation (NSF), National Institutes of Health (NIH), pertinent regulatory agencies [such as the Food and Drug Administration (FDA)], local governments, and the private sector to:*

- *Leverage research and develop policies on genetics and other biomedical research to improve diagnosis and treatment (and patient survivability),*
- *Formulate policies for developing and using neurological interventions and advanced training and education, and to mitigate our adversaries' uses of these techniques, and*
- *Protect against bioattack through biomedical research and improved cooperation among government and non-government agencies and local responders.*

4: *Treat nanotechnology as a high-risk area, with the potential for extremely high pay-off because of the immense performance enhancements possible over a wide range of applications (e.g., structural, electronic, and medical components and systems).*

II. Subsidiary Conclusions and Recommendations. S&T will have a profound effect on how we fight, once we agree to commit our forces.

A. Force Projection and Maneuver. Transport of survivable and lethal forces into and around the theaters of war will demand new approaches, because of the lack of transport aircraft and ships and the vulnerability of logistical infrastructure.

1. Several technologies will enable these approaches, including lightweight materials (perhaps through nanotechnology), miniaturization, robotics, and information and knowledge systems. Synergies and miniaturization will also be of premium value. The drive for miniaturization will continue. Microelectronic Mechanical Systems (MEMs) will be employed in electronic, biological, chemical, and mechanical roles for applications as diverse as inertial measurement units on a chip, distributed unattended sensors, integrated fluidic systems, and mass

storage devices. Its more ambitious smaller sister, nanotechnology, may become viable for a few applications that will stun the world.[7]

2. Energy will remain a big logistical burden, although reduced somewhat by radically different energy conversion and management systems for propulsion, weapons, electronics, and defense, as well as efficiencies and alternative fuels. Robotics and exoskeletons will improve mobility. By 2025, hybrid diesel or nuclear-electric ground vehicles and Navy ships will be in service. The Defense Advanced Research Project Agency's (DARPA) energy harvesting program may provide innovative solutions for smaller power demands.

Recommendations:

5: *DoD should solve the problem of transporting sufficiently survivable, lethal, and tactically mobile forces into a theater of war. This should involve the Objective Force concept of the Army's Future Combat System (FCS), the Air Force's Unmanned Combat Air Vehicle (UCAV) and their efforts to harness commercial aircraft, and the Navy's idea to pursue faster and electric-hybrid ships may also be a partial solution to this critical problem, along with pertinent enabling technologies.*

6: *Applications of new sources and power conversion of energy from the civilian world should be leveraged by the DoD. The Energy harvesting program sponsored by the DARPA, an exciting example of how energy needs may be met through tapping new sources, should be fully supported.*

7: *Advanced conventional materials that should receive special emphasis in the DoD are smart materials, biomimicry, and superconductivity.*

B. Precision Fires: Lethality will continue to grow, fed by precision munitions, improved sensors, and global positioning systems that enable us to concentrate the damage and killing, rather than broadly applying fires. But, even with all of this success, there will be problems in servicing well camouflaged, moving or buried targets.

Recommendation 8: *For more effective precision fires, DoD should reduce their cost (thus increasing availability) and make them more responsive to the engaged units. "Precision effects" weapons should be developed to provide nonlethal options.*

C. Protection. Troop protection from enemy fires, injuries, and disease will become more difficult, if only due to the increasing diversity of threats and our growing commitment to avoid casualties on both sides of the battlespace.

1. Survivability problems against enemy fires are still manifest for both individuals and platforms. Structural armors will improve incrementally through the use of advanced (and affordable) ceramics, biomimetic designs, and "special" materials. Eventually, active protection systems

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[7] For example, Professor Richard Smalley predicts that fullerene nanotubes may be the strongest material possible. Carbon-based, they are expected to possess a tensile strength in the longitudinal direction a hundred times that of steel, and a mass one-sixth that of steel. Even more astonishing forms of nanotechnology envisioned for electronic and biomedicine applications are discussed later in the report. *Out of the Box and Into the Future Conference Proceedings.*

and nanotechnologies may revolutionize armor. Advanced camouflage will become more effective across broad spectra, but these advances will vie with improvements in sensor capabilities. Technology will continue to add terms and parameters to the equation defining the balance between hider and finder. These technological solutions will be coupled with tactics that emphasize greater troop dispersion and limit the size of units exposed to direct fire.

2. Today, we lack the means to adequately discover planned biological attacks, thwart them during dissemination, detect and classify the agents, diagnose and treat those exposed during the consequence management stage within the latency period of the disease, and rapidly identify the perpetrators. Within the next 25 years we will not have solved all of these problems, although we will make strides toward using three (and possibly four) allied forces: effective sensors and sensor networks; the latency of the diseases; treatment through biomedical (e.g., genomic); and, perhaps, nanotechnology research.

Recommendation 9: *The DoD should continue or initiate the following thrusts to improve troop protection:*

- *Complement the geographical or terrain-based sanctuaries that no longer work well with technology-based sanctuaries, such as advanced camouflage and decoys.*
- *Continue the development of advanced materials for lightweight protection, especially smart materials and nanotechnology, and accelerate work on active protection and advanced camouflage.*
- *Leverage civilian research in genetics and other biomedical areas to enhance diagnosis and treatment (and patient survivability) under the most onerous conditions of war and to protect troops and populations against bioattack.*

D. Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR): Research and Development (R&D) in Information and Knowledge will be conducted principally by the private sector. Human exploitation of, and vulnerability to, information technology (IT) will continue to soar, so modern warfare will become increasingly network-centric, with faster and more effective command and control. The next wave in information technology must solve data overload by automating processes of validating and transforming data into useful information, solving plaguing software problems, improving and collaborating sensor operation, and enhancing communications. Optical, molecular, and organic processing may be available as options during this time.

Recommendation 10: *DoD should take advantage of industrial Information and Knowledge R&D and production, while developing associated systems to satisfy special military information needs, such as information security and assurance and robust wireless networks for moving platforms. Emphasis should be on applying the next generation of technology and solving the continual problems of software creation and maintenance. It is also important for the U.S. military to maintain basic operational capabilities upon the loss of C4ISR systems ("graceful degradation").*

E. **Prioritization, Funding, and Acquisition.** Even if these superb products of S&T are developed, DoD's systems of prioritization, funding, and acquisition must improve or our technological superiority will suffer.

   1. Most R&D work pertinent to the military will be accomplished by the private sector for purely commercial reasons and will be available to all who wish to purchase it. Since around 90 percent of the R&D investment is made outside of DoD, everyone on the globe will have access to an immense portion of new technologies.

   2. Aging equipment will become a major problem throughout all services (for example, the average age of today's Air Force aircraft is 22 years).

Recommendations:

11: *DoD's prioritization, funding, and acquisition procedures and processes should be fundamentally reconfigured to gain efficiencies and effectiveness, to access the best scientists and technologists to address military questions, and to gain the help of a private sector that is progressively less interested in accommodating DoD's arcane acquisition practices.*

12: *DoD should perform most defense R&D collaboratively among all interested government agencies, academia, and commercial industry, ending the tendency to compartmentalize efforts within various departments, especially as the DoD becomes increasingly reliant on commercial technologies.*

13: *The DoD should innovate ways to develop unique tools for the U.S. warrior while denying them to our enemies.*

14: *The DoD should increase its efforts to develop and implement approaches to predict and mitigate failure of aging platforms and systems and to effectively and affordably upgrade those systems through technology refresh techniques.*

I. THE OUT OF THE BOX AND INTO THE FUTURE PROJECT

This report is submitted as an integration and analysis of the *Out of the Box and Into the Future Project* (the Project), a conference and associated activities conducted at the request of Senators Joseph Lieberman, Pat Roberts, and Jeff Bingaman; and Congressmen Curt Weldon and Rob Andrews, as well as the DoD and academia. Co-Chairs and Steering Committee members are listed in Table 1. Sponsors provided both financial support and advice.

Conference Co-Chairs:
Congressman Curt Weldon (R-PA, House Armed Services Committee), representing Congress
Admiral Harold Gehman, USN (CINC, U.S. Joint Forces Command), representing Defense
Dr. Charles Vest (President, MIT), representing Science & Engineering and Academia
Conference Steering Committee:
Dr. Joe Bordogna, (Deputy Director, National Science Foundation)
Major General George Close, USA (Ret.), (Former Director, Operational Plans and Interoperability)
Dr. Craig Dorman (Chief Scientist, Office of Naval Research)
Dr. Ted Gold (Director, Joint Advanced Warfighting Program, Institute for Defense Analysis)
General Al Gray, USMC (Ret.) (29th Commandant Marine Corps)
Dr. Joe Janni (Director, Air Force Office of Scientific Research)
Major General John R. Landry, USA (Ret.) (National Intelligence Officer for Conventional Military Issues, National Intelligence Council)
Mr. Walter Morrow (Director Emeritus, MIT Lincoln Laboratory)
Major General Dean Cash, USA (Director, Joint Experimentation, USJFCOM)
Dr. Richard Powell (Vice President, Optical Society of America; Vice President for Research and Graduate Studies, University of Arizona)

TABLE 1. CO-CHAIRS AND STEERING COMMITTEE

PROJECT GOALS

The goals of the Project were:

1. To test current perspectives and generate new ideas on how science will change the nature of far-future (Year 2025) military operations. Admiral Harold Gehman, Commander in Chief (CINC), U.S. Joint Forces Command (USJFCOM), stated this task well. "[Y]our work at this conference should lay the foundation for our adoption of these half a dozen 'Out of The Box' candidates. You are all successful, Type-A personalities, used to thriving under pressure. You should be able to define the pedigree and the realm of the possible, so that we go to work on something with promise and challenge to it. This work is not for the weak-hearted. There are sure to be some failures and some rejections along the way. But we are not afraid of the future and what it brings. We are not afraid of pursuing the transformation that we know is required. We are not defensive about our platforms or our careers."

2. To help prepare the U.S. for the diverse spectrum of possible warfighting scenarios in the new century, in terms of research and development budget decisions and leveraging academia and industry. On the first day of the "Out of The Box and Into the Future" conference, Senator Lieberman said, "The military, the scientific community, and Congress must work assiduously to nurture an environment that encourages and rewards innovation. I appeal to all of you to work together to help educate and persuade Members of Congress to make the right investments, to develop the right policies, and to empower the right people, so we can turn our vision of technological transformation into reality."[8]

Later, Congressman Weldon added his endorsement. "This conference focuses in a way that we've not had in this city. All the various challenges that we expect will emerge in the 21st century and the absolute need for us to deal with those challenges, and to be thinking ahead. As some of you probably know, I travel to Russia quite frequently. I was there for my 21st trip two weeks ago when Secretary Cohen asked me to accompany him to meet with the Russian leadership. As bad as Russia's economy is today, they are still putting a tremendous investment in basic research and technology."[9]

PROJECT STRATEGY

Admiral Gehman described the conference strategy during his opening remarks. "This conference should be the beginning of a continuing process of dialogue and problem solving, not just a one-time event. We need to keep motivating and prodding our system in the right direction, and that just doesn't occur in this town with one big event. This is a marathon with a final goal to transform the U.S. military, and a single fast sprint like this early in the race will not get us to the finish line a winner."[10]

As summarized in Figure 1, Project activities were conducted in four phases: a pre-conference phase; the conference itself; a post-conference analysis, distillation, and synthesis phase; and a phase dedicated to briefing Project findings to Congress and other interested parties.

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[8] Senator Lieberman went onto say, "…the constituency for science and technology simply is not strong enough to guarantee the attention from Congress that science and technology deserve. … So I appeal to you first to play the role of lobbyist and educator. You are the core constituency. You are scientists or warfighters, but also citizens, who can and should make your opinions known to elected officials especially on issues that are as important as these. That is the way we will broaden the base of Members of Congress who are prepared to exercise leadership on these questions." See *Out of the Box and Into the Future Conference Proceedings*.

[9] *Ibid*.

[10] *Ibid*.

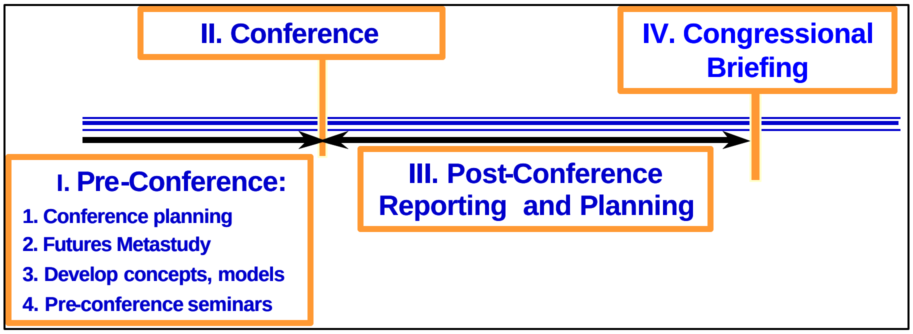

FIGURE 1. "OUT OF THE BOX AND INTO THE FUTURE" ACTIVITIES – FOUR PHASES

Phase I: Pre-conference. Pre-conference activities included a meta-study of selected futures projections performed by various agencies and individuals – all of which are listed in the biography under Appendix B.[11] During this Phase, the Institute also held a series of pre-conference seminars on subjects pertinent to the Project. Table 2 lists the seminar subjects and speakers.

1. ***Emerging Trends and Conditions – 2000-2025***: Lieutenant General Patrick M. Hughes, USA (Ret.), President, PMH Enterprises LLC
2. ***1999 Workshop on Advanced Technologies and Future Joint Warfighting***: Dr. William Hurley, Joint Advanced Warfighting Program, Institute for Defense Analysis
3. ***Maneuver and the Far-Future Battlefield***: General Al Gray, USMC (Ret.), 29th U.S. Marine Corps Commandant; Senior Fellow, Potomac Institute for Policy Studies
4. ***Joint Experimentation Program and Far-Future Military Operations***: Colonel Richard Geraci, USA, Deputy Director, Joint Experimentation Directorate, USJFCOM
5. ***The Difficulty of Getting 'Out of the Box'—A Historical Perspective on Innovation and the Modern Military Art***: Professor William McBride, U.S. Naval Academy
6. ***Likely Effects of Politics, Economics, Technology and Demographic Trends on Future Military Developments and Conflicts***: Major General John Landry, USA (Ret.), National Intelligence Officer for Conventional Military Issues, National Intelligence Council
7. ***The 20XX Games***: Michael Vickers, Center for Strategic and Budgetary Assessments with Andrew Marshall, Director, Net Assessment at the Office of the Secretary of Defense
8. ***Army S&T and the Objective Force – Accelerating the Transformation***: Dr. Michael Andrews, Deputy Assistant Secretary of the Army for Research and Technology

TABLE 2. PRE-CONFERENCE SEMINARS

Phase II: The conference. The conference itself was held on June 26-27, 2000 at the International Trade Center at the Ronald Reagan Building in Washington, D.C. Over

[11] The results of this metastudy are presented in the *Out of the Box and Into the Future Conference Proceedings*.

300 people from the military, science, industry, and government communities participated in the conference. Appendix C lists the speakers and other key participants. Transcripts and charts used during the conference appear in the *Proceedings*.

The basic motivation behind the conference was to encourage dialogue among warfighters and scientists toward understanding the potential influences of science and technology on the nature of far-future conflict. It was a worthy purpose, perhaps best exemplified by Dr. Dan Alkon in his opening remarks, "I have been lucky enough over the last decade or two to interact with defense initiatives, even though I've been at the NIH for many years. I think that an important prospect that could emerge from the discussions in this conference over the last two days is the need to interface and cooperate much more extensively between biomedical research and defense initiatives. There is a natural convergence and a commonality of purpose from a variety of points of view."[12] Similar sentiments were expressed on behalf of participants from a wide variety of disciplines.

The list of conference speakers and participants reflects the degree to which we were able to bring the military and science communities together. It was certainly an impressive and eclectic gathering – two congressional members and many staffers, ten flag officers, well-known authors (two in fiction and over ten in non-fiction), and more than twenty world-class scientists and technologists. The principal failure was in the mixing of communities, for many of the military participants only attended the first day, which emphasized warfighting. A secondary failure was symptomatic of our approach. Break-out sessions were necessary because of the many aspects of science and warfighting considered in two days, but it tended to limit the experience of participants, who had to choose among the sessions. In our minds, this makes the analysis and reporting phase even more crucial. The presentations of the speakers and ideas contributed by the attendees are virtual veins of gold covered by a mountain of transcripted discourse. Our aim here is to extract as much of that gold as possible, and to prepare to continue this dialogue.

Phase III: Post-conference Reporting and Planning. During Phase III, we have attempted to integrate information from every facet of the conference and associated activities and to draw conclusions about how the science and technologies addressed are likely to affect military operations in the 2025 arena. In accomplishing this, we employed an iterative process of data collection (observation), distillation, and analysis and synthesis. The results are reported in three publications, as depicted in Figure 2. First, the proceedings on CD-ROM include all speaker transcripts and most of the charts used by speakers (some charts were not made available). Appendices to the *Proceedings* hold the meta-study on selected futures examinations and transcripts and charts from the pre-conference seminars.

[12] *Ibid*.

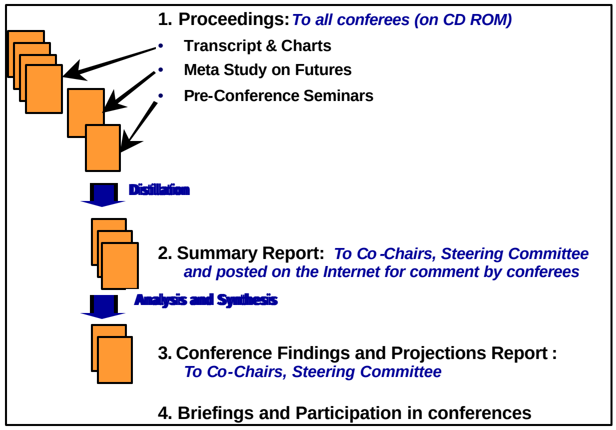

FIGURE 2. PRODUCTS OF THE CONFERENCE ACTIVITIES

The second product was a *Conference Summary Report*, distributed to Co-Chairs and Steering Committee members, and placed on the Institute's website for comment by conference attendees. The *Conference Summary Report* contains highlights from the conference, but neither analysis nor synthesis.

This report, *Out of the Box and into the Future: A National Security Forecast*, is the third publication. It is an attempt to analyze and integrate selected aspects of the various findings across the entire Project. As discussed later, we will brief these findings to the Co-Chairs and Steering Committee.

Phase IV: Congressional Briefings. Finally, the analytical report will be presented to Congress and to others. Congressional staffs will be briefed beginning in the January/February 2001 timeframe, with members receiving briefings when they return next year. The first conference to receive information from the Project was *After Globalization: Future Security in a Technology Rich World*, organized by Lawrence Livermore National Laboratory's (LLNL) Center for Global Security Research (CGSR) in December 2000.

ORGANIZATION OF THIS REPORT

In the following, we have tried to draw conclusions across all scientific and warfighting aspects discussed during the Project. Subjects of this Project were wide-ranging. There is no claim that they were comprehensively addressed, but we hope this offering will contribute somewhat to the critical mass of information and thought needed to see, however indistinctly, into the future.

The report is organized under four subject areas, shown below in Figure 3. All of these aspects are interconnected to change the face of conflict in the future, and all were addressed during the Project, although science, technology and acquisition were the principal focus. In the next few pages of this Introduction, we have summarized some of the major findings. These and related findings are presented in more detail throughout the main body of the report.

Chapters II and III offer some conclusions on world environment and military operations, respectively, with expected influences of science and technology presented under each section. Each area of S&T is discussed under Chapter IV, with general comments and Chapter V offers some thoughts on the adequacies of the processes used by DoD to acquire and field the needed science and technology. Finally, Chapter VI offers some recommendations concerning the logical next steps to be taken in the Project.

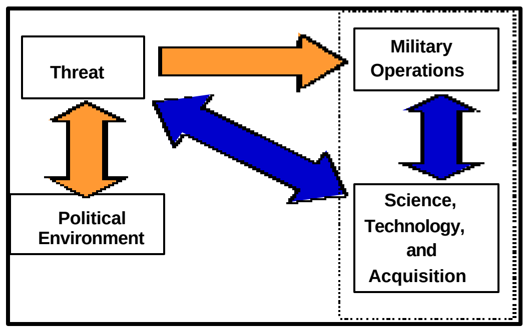

FIGURE 3. FOUR ASPECTS OF FUTURE CONFLICT EXAMINED DURING CONFERENCE ACTIVITIES

In most cases, we did not attribute information contained in this analysis to its contributor. There are two reasons for this. First, it would complicate and expand an already voluminous report. Second, in attempting the necessary synthesis, we have often applied contributed wisdom to purposes and examples beyond those used by the speakers or writers – and not necessarily agreeable to him or her. Moreover, in some instances we have reported the results of discussions conducted during one panel session or presentation under a different session because of contextual considerations. Attributions are, however, provided fully in the *Out of the Box and Into the Future Conference Proceedings*.

II. Political Environment and Threats

POLITCAL ENVIRONMENT

There have been approximately two and a half wars per year throughout written history. That's about 15,000 significant wars on the books. If you consider all wars, including civil counter regime and civil strife, there's been an order of magnitude increase in the prevalence of war over the past half century alone. That is specifically from five to fifty wars on the globe at any given time. More depressing, the death toll is equivalent to the loss of Las Vegas, Nevada for every year. Ninety percent of those losses of the last three centuries occurred in this century – 82.5 million people.[13]

If we are to believe the statistics, war is usually local and recurring. Over the past century or so, about 85 percent of wars were internal, six percent were state versus state, and the remainder was some combination. Data also show that over the past ten years there have been about 108 conflicts in 73 locations, suggesting recidivism – wars don't get resolved.[14]

A fair question is, "will this trend of increasing conflict continue?" Even a cursory glance at the existing legacy of global and local problems will persuade most that conflict and misery will continue, at least for the next quarter century. Bad borders are an example of this legacy. The establishment or revision of national borders around the world was often accomplished arbitrarily or for self-serving ends, particularly during the European Imperial Age. At the conclusion of wars state boundaries are often redrawn in order to solidify gains (e.g., post-World War II national divisions created in Eastern Europe and the Balkans). Figure 4 illustrates these difficulties by considering an emerging "solution" for Yugoslavia – a gerrymandering that may be quite defensible given the circumstances, but which carries a complex set of problems into the future. Extremely long borders, such as those between Bosnia and Croatia; many (and sometimes hostile) neighboring states (Serbia has seven); and a heterogeneous mix of ethnic and religious groups throughout all countries that once comprised Yugoslavia. Over the entire globe, border problems have resulted in separation of like or integration of incompatible ethnic groups and, borrowing a phrase from Lieutenant General Patrick Hughes, "ethno-linguistic pan–nationalism."

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[13] C.E. Noble, "Psychology of War," Draft Manuscript Chapter, University of Georgia, 1978. Ingomar Hauchler and Paul M. Kennedy, *Global Trends: The World Almanac of Development and Peace*, New York: Continuum, 1994), pp.177-184. (Of course, this may not be a large per capita increase, since the world's population has grown significantly during this period.)

[14] G. Pascal Zachary, "Market Forces Add Ammunition to Civil Wars—Research Suggests Rebels have 'Greed' as Motive," *The Wall Street Journal*, June 12, 200, p. A21.

FIGURE 4. AN EXAMPLE OF TROUBLED BORDERS

Perhaps no factor is as divisive as the gaps in living standards between the "haves" and "have-nots" throughout the world. There is sufficient literature to justify a short treatment here. Perhaps it is worth musing whether globalization will heal or exacerbate the situation. Surely, the global economy offers opportunities to many developing countries, especially those with a high percentage of young people with the energy and motivation to pursue material success.

But, the ramifications of economic and cultural globalization are not fully known and could cause major animosities and conflict around the world. Much of the world interprets this globalization as the exportation of *Western* economy and *U.S.* culture. They fear exploitation by the former and have little love for the latter. Moreover, as nations find ways to improve their competitiveness, such as improving production technologies, exploiting populations for cheap labor, or banding together to form economic blocs (e.g., the European Union or OPEC), there is a chance that U.S. dominance of the world's economy will end and we will become just "one of the crowd" economically. The Hart-Rudman study agrees.

> It would seem that the prospect of an increasingly integrated global economy lies before us. The integrative process, however, is not so simple. There are several reasons to doubt that global economic integration will proceed rapidly or smoothly. It may not even proceed at all, and it may even retreat in some areas. … As with the diffusion of technology, parts of the world are as likely to be pulled apart as brought closer together in the process of global economic integration. ... Can a world half integrated through Western techniques and technologies and a world half alienated by them stand together in an era of dissolving borders? … The ever tighter harnessing of science to technological innovation, and of that innovation to global economic integration, is changing the rules of international engagement.
>
> States have often competed with other institutions for influence beyond their borders. But the challenges now being mounted to national authority and control [by cultural and economic globalization]—if not to the national idea itself—are both novel and mighty.
>
> As global and domestic infrastructures become more indispensable to modern life, their disruption can have literally life-threatening consequences. Such infrastructures, including crucial transportation, health, sanitation, and financial systems are bound to become targets of the

> disgruntled, the envious, and the evil—individuals, groups, and potentially hostile countries alike. They will be very difficult targets to defend.[15]

Religious and ethnic differences will continue to drive wedges of violence between neighbors. The increasing mix of peoples and religions, particularly Islam, Hinduism, and Christianity, has resulted in a fearful toll that is unlikely to diminish during the period of interest.

Criminality and drugs may well increase, despite local, national, and international efforts to curtail them. Indeed, a "globalization" of crime parallels the more productive spread of economy and culture. Ethnic cleansing in Bosnia and Rwanda; the horrors of Revolutionary United Front (RUF) atrocities in Sierra Leone; terrorist groups, such as the Tamil Tigers in Sri Lanka and the ETA in Spain; and civil strife in Columbia spilling across the borders of Venezuela, Ecuador, and Brazil are examples of conflicts that may be with us for a long time.

A growing population (from six billion today to eight billion within 25 years), probable shortages of water and other resources, and AIDS and other threatening diseases, will add to these travails. Environmental concerns will become more prominent as resources and health suffer from the consequences of population growth, increased energy consumption, and conflict-generated pollution. For example, coal-burning China is upwind of Japan and Korea, with resulting transport of regional acid rain. So, for East Asia and other regions of the world, energy needs and the by-products of energy consumption may constitute grounds for conflict. Another example is the industrial pollution in many East European countries – one of the most disturbing aftermaths of communist rule.[16]

One possible scenario is based on the world's dependence on high agricultural productivity and efficient supply lines. Dr. William H. Calvin suggested during the conference that in the event of a cold wave or similar global weather catastrophe, perhaps resulting from man's careless treatment of the atmosphere and exacerbated by pervasive adoption of monocultural crops, much of civilization could be ruined over the next decade in a series of wars over the remaining food. Millions of humans would survive, but they would probably be enclaved in a series of small countries under despotic rule, all hating their neighbors because of mutual atrocities during the down-sizing. Recovery from such antagonistic gridlock would be very slow, Balkanization writ large.[17] But, even if we avoid such a world-wide tragedy in the future, our current problems will take a long time to resolve. Until we find a more peaceful way of changing these factors, the fighting will not stop.

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[15] *New World Coming Supporting Research and Analysis*, pp. 25-27, 1, 3. The second Commission references two contradictory trends ahead: "a tide of economic, technological and intellectual forces that is integrating a global community, amid powerful forces of social and political fragmentation." See U.S. Commission on National Security/21st Century, *Seeking a National Strategy: A Concert for Preserving Security and Promoting Freedom*, April 15, 2000, p. 5.

[16] Of course war, and even peacetime defense operations are environmentally destructive, although there are recent efforts to curtail some of this damage. At a presentation to the Association of American Universities in September 2000, Rear Admiral Jay M. Cohen, Chief of Naval Research, noted that the Navy has to learn to be good neighbors with the marine life around it.

[17] See *Out of the Box and Into the Future Conference Proceedings*.

So, we can expect no lessening of conflict over the next quarter-century. But, will the U.S. necessarily become engaged? Again, the question appears to be in the affirmative. The new Bush administration has committed itself to reducing the number of U.S. troop deployments, but there are too many areas where American interest may be threatened and our humanitarian empathy awakened to become too sanguine about remaining aloof. Many comprehensive treatments of these potential entanglements are available in the literature, but Table 3 lists some of the U.S. ties and interests that could be a factor for troop commitment in the future.

- Middle East
  - Oil
  - Israeli commitments
- Europe
  - Historical partnerships in trade
  - Political ties
  - NATO commitments
- East Asia
  - China's peer threat
  - N. Korea's instability, missiles
  - Trade partnerships
- India
  - Potential (nuclear?) conflicts with PakistanThe Americas
  - Trade
  - Threat of drugs, crime
- Russia
  - Instability
  - WMD/ICBM arsenal
  - Arms trade with our adversaries

TABLE 3. EXAMPLES OF U.S. GLOBAL TIES AND INTERESTS

Yet, with the growth of weapons systems lethality and power, we must continue to seek other ways to solve the global problems of mankind.[18] While the U.S. has certainly not eschewed war – our involvement in global conflict has increased over the past twenty or so years – we have begun to redefine war by trying to reduce casualties on both sides to a minimum. There are immense technological opportunities to abet this admirable strategy, such as the development of non-lethal and precision effects weapons.

THREATS

Whether or not peer military competitors emerge to initiate unconstrained (and perhaps even nuclear) war, adversaries using asymmetric weapons and threats will continue to foster effective and cheap warfare against us. And these asymmetric

[18] Although not directly in line with the purpose of the conference, David Brin's plea to find other options to settle differences is compelling. These other options may involve changing the human component of conflict. For this reason alone, advancements in human factors and neuroscience may yield the most profound results of any of the technology areas examined in this project, yet we spend little money (compared to hard sciences) to look at human behavioral aspects of war. The Neuroscience and Human Factors Panel spoke to this and possible solutions that should be further examined.

weapons will include WMD.[19] Of these, the greatest threat may be biological agents, due to their high lethality, infectivity, covertness, and availability. Over the next 25 years, the technologies of war will become increasingly deadly and efficient, from automatic weapons to WMD. In particular, the development of more effective and less expensive weapons will ultimately create better-armed adversaries. Examples are the cheap, easy to use GPS-based precision long-range munitions we are currently developing. If proliferated, these will serve the needs of asymmetrical warriors very well, particularly in view of the fact that the coordinates of many installations and facilities are readily available on the Internet.

The combination of global unrest and availability of powerful weapons has given justifiable rise to our concerns about a greater potential for a wide diversity of catastrophic terrorism against U.S. forces and citizens. The Hart-Rudman report suggests that,

> …[I]n the future our national security system will have to consider a world of chemicals and biological agents as well as nuclear weapons and conventional arms. We will find ourselves challenged with protecting the information networks on which our banking systems and public services will depend, the disruption of which could paralyze our economy and pose literally life-threatening dangers. Our potential adversaries will range from great military powers to rogue states to international criminals to malicious hackers. … The upshot of the changes ahead is that Americans are now, and increasingly will become, less secure than they believe themselves to be.[20]

So, we will be forced to find better ways to deal with the availability of increasingly lethal weapons to terrorist nations, sub-national groups, or even disturbed individuals. As the Oklahoma City bombing illustrates, these need not be advanced technology weapons. A major problem in our society is that information on how to make and use a wide variety of weapons is abundantly available on the Internet.

Abnormally violent behavioral tendencies will cause big trouble – not because individuals will have changed for the worse, but because the havoc one person with bad motivations can cause is multiplied by the powerful technologies becoming more

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[19] A seminar held under the Joint Experimentation Futures series concluded that, homeland defense becomes much more difficult with the potential of Highly Energetic Materials (HEM) to cause nuclear-like destruction and the ability of electromagnetic devices to shut down communications and transportation systems. USJFCOM Joint Experimentation Directorate, *Weapons of Mass Effect Seminar Final Report*, June 30-July 1, 1999, Prepared by the Strategic Assessment Center, Science Applications International Corporation.

[20] Moreover, according to the Hart-Rudman Commission, "Large-scale missile attacks will be able to overwhelm defensive systems, despite considerable improvements to them. American bases abroad will become vulnerable to these weapons." On the prospects of terrorism, the report is even more pessimistic. "The international norms against the spread of [WMD] are being challenged, and the global export control regimes covering nuclear, chemical, and biological weapons will not effectively keep them from state and non-state actors that are determined to acquire them. Biological weapons are the most likely choice of means for disaffected states and groups in the 21st century. … A bio-weapon arsenal can be acquired for as little as $10,000-$100,000." *New World Coming Supporting Research and Analysis*, pp. iv, 2, 50-52. "Non-proliferation of WMD is of the highest priority in U.S. national security policy in the next quarter century." *Seeking a National Strategy*, p. 8.

available.[21] An important challenge is how to protect the American people from this growing threat. Is this Homeland Defense, and does it fit under the set of responsibilities we may have to delegate to the military during the next 25 years? These threats will continue to grow and to be applied broadly, and their tactics and weapons will often blur the distinction between formal war and terrorism.

Moreover, we can no longer hope to keep new ideas and technologies from our adversaries (not even those developed in the U.S.), so we must understand and counter the prospects of these technologies turned against us. One of DARPA's missions is to avoid technological surprise, but it cannot do this job alone. For instance, skills are needed in projecting changes in military operations that may result from technological breakthroughs. A collaborative set of Proactive Red Teams is needed to predict and expand on the synergies likely to develop between our adversaries' technological capabilities and military strategy or tactics – especially those that are derived from asymmetric warfare and terrorism. We must understand these threats, and through improved doctrinal/technological experimentation, look for ways to mitigate, or where it makes sense, try to adopt them. Further discussion on the Proactive Red Team concept is offered in the next chapter.

Recommendation: DoD should establish a set of Proactive Red Teams to <u>collaboratively</u> examine and build upon these threats and strategies. Their goals would be to continuously test U.S. joint and coalition capabilities to defend against new threats and strategies and to identify any that should be adopted by our forces. Both goals will require improved experimentation processes to seek solutions through efficaciously combining doctrine, weapons, and technology, and a broader and continuous dialogue among operators, technologists, and the Intelligence community. Special attention should be paid to the likelihood that we will face our own technologies across the battlespace.

Finally, while new science and technology will continue to produce impressive benefits for mankind, they have a "dark side" as well. It is sobering to consider that, while mankind first gained the power to annihilate life over a major portion of earth with the development of thermonuclear weapons only thirty or so years ago, the first quarter of this century may well see three additional tools to accomplish Armageddon. First is the inadvertent or intentional introduction of harmful biological pathogens. During the "Out of the Box" and CGSR conferences, biomedical professionals expressed alarm that bioagents with a potential to cause pandemics would be developed with an unprecedented resilience and lethality, perhaps even targeting specific ethnic groups. Of equal concern are accidental catastrophes in a future where teenagers could easily manipulate genetic materials using simple equipment, perhaps

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[21] David Brin proposes that, "If the *Blade Runner* image proves right, we are simply doomed. The center – a complex, interdependent and lawful free society – will not hold. Failure modes will swallow us like quicksand as we rush blindly ahead, unenlightened by either foresight or resiliency." See *Out of the Box and Into the Future Conference Proceedings*. Bill Joy, Founder and Chief Scientist of Sun Microsystems, made a similar suggestion: "We're lucky [that] Kaczynski was a mathematician, not a molecular biologist." See Joy, *Wired*, April 2000.

to create an exotic pet. The next chapter discusses this threat and its possible mitigation.

Another growing potential for global disaster was mentioned earlier. Man's increasing impact on the earth's atmosphere has perhaps been underplayed because solutions will negatively affect lifestyle, especially in developed countries. The unavoidable truth is that we have dramatically changed the composition of our air and, aside from evidence provided by improving, but still crude models and empirical data on growing weather variations, we do not know how extreme the consequences might be. Moreover, long-standing research projects on how to intentionally manipulate local weather (which will certainly cause significant global effects) may lead nations to change weather patterns to their advantage – and to the detriment of their neighbors. Although manipulation of weather may not be successful over the next 25 years, there is little chance that we will significantly reduce the rates of consumption-generated atmospheric changes, which may well manifest in serious global problems.

Finally, the confluence of self-replicating nanotechnology, new biological techniques, and cognitive computing may present challenges that we will ignore until we find ourselves facing a billion "nanofrankensteins," each fully capable of reproduction. Further discussions of this scenario are offered in Chapter IV.

Of course these scenarios may turn out to be fictional. Too many unknown or poorly understood variables in too many interdependent equations make prediction difficult. But, the severity of consequences should even a small part of them occur demand that we constantly address their potentialities and likelihood.

III. Military Operations

GENERAL

Projecting the nature of future military operations has conventionally begun with a description of current operations, conceptually shown in Figure 5 as the top of the "lowest stool." The vision of the future is developed by predicting changes introduced by mutually braced "legs," representing new doctrine, threats, and enabling science and technologies, which change the details of military operations, shown schematically as figures on the stool. This model works well as long as there are no revolutionary developments in these three factors. For instance, a radical scientific trend may cause equally radical changes in the warfighting scenarios of tomorrow. This new paradigm, as it relates to science and technology, is discussed in Chapter IV.

While advancements in S&T have had major influences on changing military operations, these changes are often made belatedly. Examples of military tradition overriding good sense in the face of new technology are numerous throughout history. The Europeans clinging to highly massed army formations long after the rifled bullet had made such tactics unwise, is just one. The initial decision to adopt an often expensive and disruptive technology to improve military capabilities is most generally sustained by national priorities, international affairs, and, to a lesser extent, a desire to exploit a new technology.

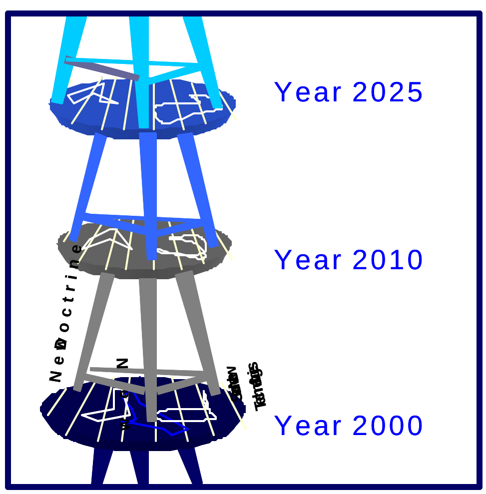

FIGURE 5. FOUNDATIONS OF BATTLESPACE CHANGE

The essence of war is not likely to change in the next 25 years. Application of strength to weakness will always be a reasonable strategy, tactical and operational surprise will remain a vital attribute of maneuver, and underestimating the enemy will continue to be a luxury one cannot afford in combat. But, there will certainly be important changes in the context of conflict. According to *Joint Vision 2010 and 2020*, accelerating rates of change will make future environments more unpredictable and less stable, presenting our Armed Forces with a wide range of plausible futures.

We must be able to operate successfully in all of these possible environments – to handle the entire spectrum of conflict, from terrorism to nuclear war. This calls for careful prioritization of our resources and time. We can expect a wide diversity of situations and players in conflicts (joint, coalition, and interagency against state and non-state adversaries), the nature of which will be difficult to predict. As a result, we must develop broad capabilities and skills. Nobody optimizes better than we do, but optimization centers on point solutions and our world will not offer problems that are sufficiently predictable and bounded to always respond to point solutions. At the same time, limited resources will force trade offs in how (and how often) we enter conflicts. For example, the latest report from the Hart-Rudman Commission questions the concept of readiness based on participation in two major theater wars – an issue that will undoubtedly continue to be in dispute.[22]

Recommendation: The U.S. military should prepare itself for the full spectrum of conflict. This calls for careful prioritization of our limited resources and time to concentrate on the most likely scenarios, without neglecting those that are less likely. It also adds even more emphasis to the need to conduct operations in a joint and coalition environment.

Constrained operations, such as wars of limited objectives, humanitarian assistance and peacekeeping will probably be the largest part of U.S. forces activity. Homeland defense, in the face of terrorism, and especially bio-terrorism, will become a necessary mission for the military. After 50 years of conducting constrained operations, we are still learning lessons (some of which we have learned over and over). For instance, our Kosovo operation was certainly successful, but it was conducted at great cost and was reportedly less than effective against military targets. Although battle damage estimates vary dramatically, it is now widely believed that we destroyed only 14 tanks. In fact, controversy continues as to whether we forced Milosevic to quit because of his loss of military systems or because of our destruction of civilian infrastructure, such as power grids. An important question is, "can we afford to pursue Kosovo-style operations with 38,000 air sorties, costing $2-3 billion and another $2-3.5 billion per year for peacekeeping troops?" DoD's After-Action Report suggested that the Department needs $3.5 billion to improve the approaches used in Kosovo: precision strike; electronic warfare; and intelligence, surveillance, reconnaissance.[23]

And, according to the Defense Science Board (DSB) – we will fight in urban areas more frequently in the future. "Urban environments are no longer avoidable for U.S. and coalition forces. … The ability to control and dominate urban areas, the freedom of maneuver in urban areas, and the capability to discriminate between non combatants and combatants are critical enablers of effectiveness in many likely

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[22] *Seeking a National Strategy*, pp. 14-15.

[23] Office of Assistant Secretary of Defense, *Joint Statement on the Kosovo After Action Review*, October 14, 1999. See also Center for Strategic and Budgetary Assessments, *Total Cost of Allied Air Force Campaign: Preliminary Estimate*, June 10, 1999.

scenarios."[24] Urban combat can be an especially deadly fighting environment, which often blunts the effects of conventional warfighting systems and tactics. Both the Army and the Marine Corps are currently examining their requirements. Clearly, special fighting gear and surveillance and communications equipment will also be needed. We will develop and deploy ever more sophisticated less-than-lethal weapons in our efforts to restrain or channel adversaries we do not wish to kill or injure and to reduce collateral damage and injury to civilians. Less-than-lethal development spans a broad range of complexity, from rubber bullets and sticky foam to directed energy systems. A class of chemicals called "calmatives" may eventually be used against aggressors in all levels of conflict as we gain an understanding of the brain and can apply pharmaceuticals to affect its workings without doing permanent harm. Better policies are needed to guide the development and use of such weapons. Without these policies we will use them poorly, or as in Somalia, not use them at all.

Recommendation: DoD should increase its emphasis on fighting effectively in urban areas.

Successful response to changing environments, threats, and technologies will demand the adoption of flatter commands with greater connectivity across DoD and other agencies. This goal will be enabled through new organizational structures and operations and advancements in, and proliferation of, information systems, often replacing "middle management" with software. With the help of the same technologies, joint and coalition operations will become normal.[25] The balance between sharing and denying information access and the need for dispersion will C4ISR problems harder. But, information and knowledge systems will change many features of military operations. Examples are defining state borders electronically, rather than geographically and dramatically reducing the time necessary to prepare for situation-specific combat.

Over the next 25 years, we may become able to fundamentally change the warfighter through pharmaceuticals. As our knowledge of the brain grows we could develop drugs that will temporarily enhance memory, courage, strength, or mental agility – custom-tailored and free of side effects. The advantages of performance-enhancing drugs are obvious in combat, but there are some significant ethical and policy issues. First we will have to decide if this is an acceptable practice. If so, policies must be developed to control the use of chemical enhancement. Whether or not the U.S.

[24] DSB, *Joint Operations Superiority in the 21st Century,* Volume I Final Report, October 1998, page xiii.

[25] Senator Lieberman stated that, "The Armed Services Committee of the Senate, on which I serve, has tried to give some meaning to the idea of jointness in the military these many years after Goldwater-Nichols passed and set that goal for us." See *Out of the Box and Into the Future Proceedings*. Joint Vision 2010 indicates that, "Simply to retain our effectiveness with less redundancy, we will need to wring every ounce of capability from every source. That outcome can only be accomplished through a more seamless integration of Service capabilities. To achieve this integration while conducting military operations we must be fully joint: institutionally, organizationally, intellectually, and technically. … We must find the most effective methods for integrating and improving interoperability with allied and coalition partners." Chairman of the Joint Chiefs of Staff, *Joint Vision 2010*, pp. 8-9.

adopts a policy to use performance-enhancing drugs, we should prepare for their use by our adversaries.[26]

A more acceptable change to be derived from our increasing understanding of the brain's functions will be an improvement in our education and training processes. Dr. William Calvin predicts that within the next 25 years we will be able to approach education with the same degree of scientific knowledge (as opposed to empiricism) that we possess today in medicine, which he suggests is about 50 percent. If so, we will be able to train warfighters better and more quickly than current understanding allows.

Recommendation: DoD should collaborate with NSF, NIH, the private sector, and FDA and other regulatory agencies to formulate policies for developing and using precision drugs and advanced training and education, and to mitigate our adversaries' use of these techniques.

These and other profound changes will demand continuous analysis and trial and error to find the right course for military operations. But, in warfare, as in business, we are often poor at thinking strategically, even though we realize the importance of envisioning and pursuing what we want to look like in 25 years. In the context of this report, this means using foresight in applying S&T to expand our ability to influence the battlefield. However problems and solutions present themselves, the perspectives of the warfighter and the scientist often differ dramatically.[27] Both visions must be considered, since neither represents complete truth. An important approach is experimentation, through concepts such as "doctrinal prototyping," in which military operations are developed in concert with new or redefined threats and enabling technologies. Currently, through the employment of jointly conducted experimentation, we are developing the necessary understanding of synergies that exist among these aspects of military operations. These ideas began with the battle laboratories and are continuing under the USJFCOM's Experimentation Directorate. We need to improve experimentation processes, where tactical and strategic doctrine are varied against a range of weapons technologies and design parameters to get both right.[28] New concepts are being examined at the battle laboratories and in exercises conducted at 29 Palms, George Air Force Base, Newport, Langley, and Fort Hood. These concepts should significantly reduce the cycle time for introducing new systems and tactics into the field, while ensuring that they are the right solution to future problems. In addition to this effort is the need to develop the Proactive Red Teams mentioned earlier. These teams would examine emerging threats, threat operations,

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[26] Another possible use for these drugs will be as an aerololized nonlethal weapon to induce passivity among targeted personnel.

[27] For example, during a conference discussion of robotics on the battlefield, it was noted that the military thought of these technological advancements as enhancements to or augmentations of existing human-based operations and strategies, while scientists more often viewed them as replacements for human presence on the battlefield.

[28] During the Information and Knowledge Panel, Dr. Steven Cross asserted that whenever he managed to get technology into the warfighters' hands early enough for them to train with it, they developed new doctrine and better ways to use it, or modified the technology to fit the need. See *Out of the Box and Into the Future Conference Proceedings*.

and technologies in order to fully define, develop, and integrate them into concepts that challenge and improve our military responses. Those concepts that work best may even be adopted by U.S. forces.

MANEUVER & POWER PROJECTION

"Maneuver warfare thought process," is a philosophy that demands both a strong command structure and empowerment of the warfighter to operate successfully in the fog of war. General Al Gray suggested that training and guidance that teaches young lance corporals or sergeants to think is different from that which merely teaches them to act. The need to move quickly into and around a theater of war will grow during the next 25 years, especially if military threats we face become more challenging. Major problems in moving into the theater include growing difficulties of transporting robust forces, and defending our logistical "tail." According to the Hart-Rudman Study, "In recent years, and despite the military downsizing that followed the Cold War, U.S. troops have operated in over one hundred different countries. The American people appear to support this posture. … Other studies characterize public support for an active American role in the world as one of 'supportive indifference'."[29] The DSB indicated that this global involvement is likely to continue and discussed how to be successful in world-wide engagements:

> Early and continuous combat effectiveness is characterized by the ability to: deliver potent military power within hours, anywhere in the world; follow-up with more potent capabilities, including ground forces, within 24 hours; and sustain and augment these forces, including establishing regional operating bases – some being sea-based – even when there is limited local infrastructure. … Core capabilities essential to achieving [this] are: air, space, land, and sea forces that can deploy near-simultaneously from peacetime stations and operate from dispersed posture to minimize targets for enemy mass casualty weapons and quickly seize control of the situation; joint doctrine [to guide this effort]…; agile ground forces…; and service support arrangements that maintain total asset visibility and make depot-to-depot user deliveries…[30]

But, this means that we must somehow get sufficiently *lethal and survivable* forces rapidly into the battlespaces of tomorrow.[31] A shortfall in carrying-capacity will

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[29] In addition, this study reported that, "Since the end of the Cold War, the United States has embarked on nearly four dozen military interventions in the past decade as opposed to only 16 during the entire period of the Cold War." Supportive Indiffernece is defined as little feeling for or against most foreign policy or defense issues as long as they exact no great cost in blood. *New World Coming Supporting Research and Analysis*, p. 127.

[30] *Joint Operations Superiority*, pp. ix-x.

[31] The Joint Forces Experimentation Futures program, agrees. "The principal challenge for power projection operations in the 2030 timeframe will be the application of significant force quickly and precisely anywhere in the globe." USJFCOM Joint Experimentation Directorate, *Futures Spring Seminar Game One, Global Power Projections Seminar Game Final Report*, June 2-4, 1999, Prepared by the Strategic Assessment Center, Science Applications International Corporation, p. 2.

"The speed, mobility, and required timing of future U.S. forces may severely stress logistics capabilities. Technical innovations, such as alternative fuels, advanced propulsion techniques, precision persist into the future, in terms of both weight and bulk. For example, there will be little change in our strategic airlift force and aerial tankers between now and 2025.[32] Similarly, we can expect fewer, rather than more, Navy ships at our disposal.[33] A technical and operational challenge is to produce systems that are smaller and lighter than today's legacy systems, but are at least as survivable and lethal. These systems must also make lower logistical support demands, and of course, must be affordable.

The Army's FCS is an attempt to develop just such a force, configured to provide strategic mobility to seize and defend. It is a broad approach that employs various surveillance capabilities, precision fires, and a mix of small armored vehicles, some of which are unmanned. The Army hopes to iterate this solution into a highly mobile and agile force, for moving overseas and within the theatre of operation. This more holistic approach to acquiring a transportable, integrated combat capability is an important part of the Army's future. Open architecture, an eye on harnessing technologies emerging from the commercial sector, and the ability to move quickly and decisively through a responsive prioritization, funding, and acquisition process (discussed further in Chapter IV) will all be keys to success.

The advancement of conventional materials will provide small enhancements in weight reduction to address some transport and mobility problems. But, real solutions are likely to come from adopting entirely different approaches to survivability, such as advanced camouflage, active defense, and robotics. An important exception may be found in the immense strength-to-weight potential of nanotubes, which if realized, will allow equipment to become smaller, lighter, stronger, and penetration-resistant to degrees hitherto unimaginable. Improved transportability sought under the FCS program will benefit from better structural materials and armor, and from smart or intelligent materials that will send a warning of imminent failure or automatically react to the environment. But, survivability might suffer from the development of higher energy density explosives. At the end of this technology spectrum are metastable explosives that may even cause trouble for nanotechnology breakthrough materials.[34] Exoskeletons could greatly increase the

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effects, reach-back capabilities, and other weight/matter reduction advances could be key components in alleviating this stress on logistics. … Even with the reduction in the future force footprint, the need for rapid, timely lift will strain joint capabilities. … Space logistics is a new realm that needs further exploration." USJFCOM Joint Experimentation Directorate, *Joint Force After Next Fall Wargame Final Report*, October 18-22, 1999, Prepared by the Strategic Assessment Center, Science Applications International Corporation, pp. v-vi.

[32] According to General Fogleman, "…in my former life at CINCTRANS, I had the opportunity to look at the future of air and sealift and I came to the conclusion that between now and 2025, there's going to be very, very little change in our sealift force, strategic airlift force, and in our aerial tanker business. The opportunity exists to upgrade the tanker force through the adaptation of a commercial aircraft, but I think budget pressures are going to work against this concept." *Out of the Box and Into the Future Conference Proceedings.*

[33] On September 29, 2000, the Defense Press Service reported that ADM Vern Clark, Chief of Naval Operations, stated that the planned building of "between six and seven ships per year is inadequate to sustain the rate called for in the 1997 Quadrennial Defense Review. The Navy needs about ten ships per year Clark said" Jim Garamone, "Chiefs Tell Senate DoD Needs Money for Modernization," *American Forces Press Service*, September 29, 2000.

[34] According to the DSB, "Molecular decomposition techniques have been recognized for years as the first step in attaining a greater energy density than traditional high energy explosives. Metastable solid

mobility of dismounted ground troops, but these also have significant weight and power challenges.[35]

Fuel accounts for about 70% of the tonnage shipped to combat locations. According to Dr. Robert Bill, an armored division currently consumes approximately 600,000 gallons of diesel fuel per day.[36] Future global geopolitical environments, short lead times, and increased fuel requirements pose severe problems for future deployments. The Army is considering three intertwined approaches to reduce fossil fuel needs: alternative fuels, different energy conversion/transmission, and fuel-efficient technologies.

Certainly, techniques for improving efficiencies will be developed and applied over the next 25 years. Long-term Army goals include a 75% fuel efficiency for combat systems, and a 30% real fuel cost savings. The Army is investigating the merits of five fuel-efficient technologies: propulsion (e.g., hybrid drives, energy storage systems), advanced materials and structures, armor (e.g., active protection systems), advanced platform concepts [e.g., unmanned air or ground vehicles (UAV/UGV)], and usage and tactics.

Alternative fuels are available now. But there are some problems with this solution. For example, DoD's strong "one fuel" policy will make it difficult to move away from J8, aviation's fuel of choice. Moreover, as discussed in Chapter IV, under the section on energy, each alternative fuel introduces its own difficulties, as well as advantages.

Radically different energy management systems for propulsion, weapons, electronics, and defense will be available within 25 years. Many (certainly hybrid propulsion systems and fuel cells) will be in use in the civilian sector. The benefits of stealth and range afforded by alternative energy sources such as batteries and fuel cells are vitally important. Navy ships will eventually become all-electric, perhaps powered with electricity generated from hydrogen fuel cells, in turn fueled from off-shore hydrogen processing and refueling stations.[37] Survivable and affordable power projection via deep-water subs may become a reality within this time frame, as will unmanned underwater vessels (UUV). In addition, the Navy may pursue the merits of less expensive, much faster, ships.

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states of nitrogen are known to liberate 4-fold greater energy upon reversion to the gaseous state than combustion." Triggered nuclear isomers and micro-power sources were also discussed. DSB, *21st Century Defense Technology Strategies*, Volume I, November 1999, p. D-11.

[35] In the 20XX and Revolution in Military Affairs (RMA) wargames conducted for Mr. Andrew Marshall at the Net Assessment Office in the Office of the Secretary of Defense, exoskeletons were found to be an especially effective device.

[36] Cost is another interesting facet of the military's fuel problems. During peacetime, diesel costs about $13 per gallon from the wellhead to the tank, and it may be as high as $600 per gallon for overseas operations. In the future, cost of fuel for military operations will not increase much, since this cost is dominated by the logistical burden and not in the wellhead price. See *Out of the Box and Into the Future Conference Proceedings.*

[37] RADM Jay M. Cohen, Chief of Naval Research, indicated to the Physical Sciences and Engineering Working Group of the Association of American Universities on September 12, 2000 that, "during this decade the Navy will move to an all-electric ship and within the next 3-4 years, to an all-electric Navy."

Even a cursory look at ideas for the future battlespace, such as robots, exoskeletons, and new C4ISR systems convinces one that portable power remains a principal shortfall.[38] All of these energy concerns will not be satisfied during the next 25 years, but some important progress will be made. Energy-harvesting, along with increased efficiencies, has the potential to equip individual soldiers with the latest electronics and can enable widespread robotics and sensor operations. In this DARPA program, raw energy sources can be tree sap, bio-fuel cells (directly from the blood stream), heel strikes, or buoys and "synthetic eels," which are moved and excited by ocean currents to produce electricity.

Miniaturization of equipment will affect many aspects of force projection and mobility. It will reduce weight and bulk for individual combatants and platforms alike, and the logistics required for support of both. Recently, an Institute for Defense Analyses workshop suggested that,

> …developments [in miniaturization] profoundly affect the prospects for new capabilities at lower cost in all areas: information technology; quality and endurance of spacecraft; mini- and microvehicles with substantive capabilities; portable systems that significantly enhance an individual soldier's ability to sense and communicate; more deployable and more stealthy systems; embedded sensors for monitoring the status of personnel or equipment; and tagging… Key technical issues are how to connect to the larger-scale world and maintain ruggedness and endurance without sacrificing the advantages of smallness. … Sensors and tagging are two examples where innovative applications of nanotechnology systems are feasible. … Work continues in this area, and, once achieved, commercialization will be rapid, and the technology will become globally available.[39]

Robotics will become a growing part of the maneuver and reconnaissance force. Nearly all sources in both the warfighting and S&T communities agree on this point. Robotics will be embedded in land, sea, undersea, ground, and space platforms, with more and more prerogatives given them during the next 25 years.[40] But, while robotics has been justified on the basis of cost, replacement of humans in dangerous mission areas, and miniaturization, the major criteria must be effectiveness. As long

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[38] "Power generation is a central enabler in every area. It is a key driver of size, capability, and endurance. A key technical issue … is whether alternative technologies, such as fuel cells, will replace batteries for many applications." William J. Hurley, Phillip Gould, and Nancy Licato. *Workshop on Advanced Technologies and Future Joint Warfighting*. Summary of Proceedings from April 8-10, 1999 Workshop. Institute for Defense Analysis. June 1999, p. 4.

[39] Hurley, pp. 3-4, 9.

[40] For example, the DSB suggested that, "The ability to 'see' and kill anything within a 250 nautical mile 'tactical bubble' is an operational goal, which can be supported by tactical unmanned aerial vehicles under the control of each J-ROF commander. Thus, multi-sensor-equipped UAV systems will be needed in a variety of environments to perform a range of surveillance and targeting missions as well as enable new capabilities including precision strike and communications relay. Eventually, UAVs will serve as a weapon carrier. Systems like Global Hawk, with a ground moving target indication radar capability, and the joint, interoperable Tactical Control System, which is a common control for all UAVs, will contribute to realizing extended UAV capabilities that are supported by this study." *21st Century Defense Technology*, p. 16.

as humans are more effective in successfully completing a particular mission, it will be difficult to substitute a solution with lesser capabilities. War is, after all, about winning, and no one chooses an inferior weapon when a more capable one is available. How long will it be before robots are able to "think" well enough to take over general responsibilities in battle? The Information and Knowledge and Neuroscience Panels have suggested that may occur within the next fifty years.[41]

Recommendation: DoD should solve the problem of transporting robust forces into a theater of war, ensuring sufficient lethality, survivability, and mobility. The Objective Force concept of the Army's Future Combat System is a good example of the transformation needed, as is the Air Force's UCAV and their efforts to harness commercial aircraft. The Navy's idea to pursue faster and electric-hybrid ships may also be a partial solution to this critical problem. Some pertinent technologies are listed above.

FIREPOWER

We have sought ways of conducting limited war with minimal loss of troops for at least 50 years. A solution was to adopt overwhelming firepower. Mainly as a result of this and the threat of massed Soviet armor, we have developed awesome munitions against both area and point targets. Since then these weapons have been proliferated, along with developments from other countries to make it extremely challenging to conduct conventional maneuvers in modern warfare.[42] An interesting comment on this situation comes from the Army After Next (AAN) study, which asserts that, if not corrected soon, the current emphasis on firepower at the expense of maneuver may result in a protracted war characterized by stalemate, attrition, and unacceptable loss of life on both sides. In World War II an average of 18 direct-fire rounds were needed to kill a tank at 800 Yards. During the Arab Israeli war the average was two rounds at 1200 Yards, and in Desert Storm it became one round at 2400 Yards.[43]

Indirect fire has undergone an even more impressive improvement in accuracy.[44] For years, stand-off munitions meant servicing targets with large volumes of relatively

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[41] Joint Experimentation Futures Workshop Number One, featuring discussions on autonomous operations, concluded that, artificial intelligence will not be sufficiently robust until 2050. Under some conditions robots may still be better than humans (where situation is characterized by: dull, dangerous, dirty, denied access), but not where knowledge has to be gained by experience (e.g., complex situations). USJFCOM, Joint Experimentation Directorate, *Futures Workshop Number One: Autonomous Operations Final Report*, March 1999, Prepared by the Strategic Assessment Center, Science Applications International Corporation.

[42] According to Joint Vision 2010, "the combination of technology trends will provide an order of magnitude improvement in lethality." See *Joint Vision 2010*.

[43] United States Army, *Knowledge & Speed: The Annual Report on the Army After Next Project*, July 1997.

[44] A recent MIT study agrees, "Integrated Global Positioning System (GPS) and Inertial Navigation System (INS) guidance will soon solve the fixed target problem. … If the U.S. military is vigilant and aggressive in developing and protecting GPS/INS, it will be able to guide weapons of any range, precisely, day or night, cloudy or clear, to any point on the surface of the earth. …[I]t will simply be a matter of assigning the right payload to assure that the target will be within that weapon's lethal radius."

inaccurate fire, often causing considerable collateral damage and civilian casualties. Today's precision fires allow us to concentrate the damage and killing. For this to be effective, we need to reduce the cost of these munitions and make them more responsive to the engaged units. In some situations, even the limited collateral damage inherent in precision fires are unacceptable and we turn to "precision effects," with such emerging weapons as directed energy and electro-magnetic pulse that are meant to be non-lethal.

In the meantime, there are still major problems in addressing remote targets. Finding moving or well-camouflaged targets is difficult.[45] There is still enormous latency in our indirect fire systems. This problem inhibits our ability to satisfactorily service moving targets and can be reduced through advancements in distributed or networked operations, applications in command and control, more automation and mobility, and faster munitions**.** Penetrating and destroying deeply buried targets is still a challenge – and depth dependent – even with the advanced materials and designs used in today's earth penetrators.

There are numerous development programs to improve sensor and guidance systems from advanced materials, nanotechnology, and nano-electronics – S&T efforts that will continue to enhance our ability to detect, engage, and hit targets from greater distances. Faster munitions could result from S&T work in advanced propellants for both indirect and direct fire munitions. New levels of energy density may be reached through research on chemical or molecular forces. For example, metastable compounds could revolutionize both ends of a missile – propellant and warhead. Dr. Hans Mark offered a report of progress on the electromagnetic (EM) gun during the conference. In his opinion, this is a technology that will become viable during the next ten to twenty years – considerable research is being conducted at the University of Texas. The realization of efficient, room temperature superconductivity, discussed under Advanced Materials in Chapter IV, would improve the chances of the EM gun considerably.

Recommendation: For more effective precision fires, DoD should reduce their cost (thus increasing availability) and make them more responsive to the engaged units. "Precision Effects" weapons should be developed to provide nonlethal options.

Owen Cote, Jr. *Mobile Targets from Under the Sea: New Submarine Missions in the New Security Environment*, Massachusetts Institute of Technology, Security Studies Program, December 14, 1999, p. 3.

[45] The DSB agrees. "Today we have great difficulty in finding, identifying, tracking, and striking targets that move; finding fixed targets protected by camouflage, concealment, and deception; and achieving low sensor revisit times and target cycle times." *21st Century Defense Technology*, pp. 1-6. But, according to 20XX studies, "at this point, 'Finders' are ahead of 'Hiders'." *20XX and Revolution in Military Affairs: Various briefings*

PROTECTION (Survivability against enemy weapons, disease, and injury)

This section presents ideas on how we will use advanced science and technology during the next quarter century to protect individuals and systems. We also discuss the protection of individuals against disease and the effects of exposure to biological agents. The principal assumption is that enemy fire (projectiles or blast), naturally occurring disease or injury, biological warfare and terrorism, or coping with the rigors of combat will all become greater challenges as weapons and battlespace conditions become more complex and destructive to the individual warfighter.

Enemy Fires. Wars cannot be fought without danger, injury and death. But, our desire to limit casualties, while winning the battle, will persist. Yet, survivability problems are still manifest for both individuals and platforms. Structural armors will improve incrementally through the use of advanced (and affordable) ceramics, biomemetic designs, and "special" materials and designs that cannot be discussed in this forum. Eventually, active protection systems and nanotechnologies may revolutionize armor.

Advanced camouflage will become more effective across broad spectra, but these advances will vie with improvements in sensor capabilities. Technology will continue to add terms and parameters to the equation defining the balance between hider and finder. These technological solutions will be coupled with tactics that emphasize greater troop dispersion and limit the size of units exposed to direct fire.[46]

A result of the proliferation of technology in the next century will be the elimination of sanctuaries that are based on geography and/or distance. Thus, according to a Joint Experimentation Directorate study, many sanctuaries of the future will have to be created through the application of technology. Again, dispersion, a major approach to sanctuary, may demand organizational changes.[47]

Infantrymen constitute a large portion of the combat casualties. We must develop technologies that reduce their risks and improve their effectiveness.[48] Their casualty rates may well be higher in the future, especially if we fight in cities.

Survivability of fixed assets, and to a lesser extent, slow moving but visible assets, such as surface ships, may also become problematic. This concern stems from general access by numerous countries to excellent reconnaissance from space and the development of better cruise and sea-skimming missiles. 20XX studies concluded that a major shift in this balance is occurring in anti-ship weapons and sensors that

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[46] "The potential proliferation of NBC weapons and the advent of other WME options could make massed formations of any kind a remnant of the past. In 2030, U.S. forces may have to conduct highly distributed operations." *Weapons of Mass Effect*, p. 5.

[47] USJFCOM Joint Experimentation Directorate, *Operational and Strategic Sanctuaries Workshop Final Report*, August 10-12, 1999, Prepared by the Strategic Assessment Center, Science Applications International Corporation.

[48] Major General Robert Scales suggested that the number is 67 percent. General Paul Gorman suggested that the DoD spends a lot of money on sensors and communications to keep the headquarters in the rear in business – and that we need to do more to help the people on the front lines. Part of this solution may be the incorporation of robotics and information technologies. See *Out of the Box and Into the Future Conference Proceedings*.

can keep the Navy far offshore and deny access to the littoral areas. Solutions will include undersea vehicles, dispersion, stealth, and missile defense.[49] In fact, this threat alone may be sufficient to make missile defense the Navy's largest growth area for the next ten years. Other ideas that may be important for the Navy in 2025 are: robotics, low cost cruise missiles, and UUVs.

Biological Warfare and Terrorism. A reasonable question to pose is, "could the bioattack advantage shift to defense within 25 years?" Professors Joshua Lederberg and George Whitesides have developed what the Biomedical Panel called the nine-fold way for dealing with biological attacks. These steps are helpful in planning an effective layered defense against bioagents, being developed for implementation. Effective sensors and sensor networks, the latency of the diseases, and treatment are key ingredients in defending against biological attack. Another ingredient, suggested by Secretary Harold Smith, is to create uncertainties of success in the minds of would-be terrorists.

Today, we lack the means to adequately discover planned bio attacks, thwart them during dissemination, detect and classify the agents, diagnose and treat those exposed during the consequence management stage, and rapidly identify the perpetrators. Within the next 25 years we will not have solved all of these problems, but we will make remarkable progress.[50]

1. Treaties. Biological weaponization must be developed and tested secretly – that makes it more difficult for the perpetrator. The developer cannot be sure that he will not get caught. And the better our intelligence, sensors, and sensor networks, the greater the chance is that he will be caught.

2. Intelligence. By definition, every biological weapon agent has its own DNA that we may be able to read quickly in 25 years. If so, the analysis of a developer's blood may be far more valuable than his testimony, because his blood may carry the antibodies of the agent he has been working on. Improvements in general sensors and information and knowledge systems should improve the intelligence aspects of biological terrorism and warfare defense. Better connectivity among local and national responders will help considerably to coordinate and focus activities of the local and federal governments and non-governmental organizations (NGO) on the problems of countering terrorism in general. This system of organizations, infrastructure, and the enabling policies to make it all work must support collaborative solutions for all stages—from pre-event surveillance through consequence management—while taking care not to infringe on constitutional rights of privacy. While S&T will provide important solutions to this problem, the sociological problem of getting people and organizations to work together has no technological answers.

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[49] *20XX and Revolution in Military Affairs: Various briefings.*

[50] According to the DSB, "A biological attack on a major population center could mean that 10s or 100s of thousands of people would suffer from casualties or be affected by contaminated or sick people. That creates an enormous logistics problem, for which neither the U.S. nor any other nation is prepared. … Major deficiencies currently exist in biothreat surveillance, detection, and protection capabilities, including gaps in current information and intelligence capabilities and knowledge – spanning the spectrum from weapons production to deployment." *21st Century Defense Technology*, pp. D1-3.

3. Passive Protection. Given warning and characterization, there are many effective steps that can be taken. First, local state and federal authorities must establish credibility with affected citizens. These citizens must be persuaded that actions are being taken to mitigate the effects of the event. This step allows officials to initiate evacuation and quarantine without panic. Some other steps are dictated by common sense, such as ensuring that ventilation systems are closed. This action will often protect people inside structures. Within 25 years, affordable protective gear that can be worn during military operations should be effective against many of the bioagents to be encountered, although access to that gear will still be problematic.

4. Warning and Characterization. We will develop advanced biosensors capable of warning of a biological attack soon after threat agents are disseminated. Genetics research will provide an answer to pathogen classification, perhaps aided by rapid genome sequencing made possible through nanotechnology-based systems. Advanced diagnostics and computational models will allow us to pinpoint release points and times of release, and predict diffusion of bioagents if an attack is perpetrated against our citizens or troops. Understanding the molecular epidemiology of the agents at the top of the threat list is critically important for identifying the organisms accurately and differentiating local from exotic strains. Current databases are inadequate for this purpose and little effort is being made to fill in the gaps. Complete genome sequences of the most threatening pathogens should be accomplished.[51]

5. Vaccination. We are already vaccinating our troops against anthrax. In 25 years, vaccinating the public is possible, but can we develop and store vaccines for all possible diseases? Dr. Claire Fraser argued that genomics provides a new starting point for accelerating vaccine development.[52] Another approach to developing vaccines, suggested by Dr. Stuart Kaufman, is the use of molecular diversity. As discussed later, nanotechnology can also play an important role.[53] It should be remembered, however, that an extensive regulatory process must be completed before using a new vaccine.

6. Incident Response. Just as trained firefighters understand not to pour water on oil fires, trained biological incident responders must know where to go and what to do. Again, it is critical that sensors and sensor networks, coupled with appropriate (and available) databases, identify what kind of agent the responders are up against.

7. Therapeutics. Antibiotics and vaccines can be effective against most diseases if given soon enough. With advanced sensors and sensor networks we could have days of notice to deliver them – not sufficient time for the development of either

[51] For patients presented at a doctor's office or in the hospital with a particular infection, it can often take days before the infectious agent is identified and the appropriate therapy can be determined. But, contained within the DNA sequence of all of these pathogens are very unique signatures that could potentially be used to speed up detection and make an identification. We can now print over 30,000 individual genes on a microscope slide and we may do much better in the future. It's not at all inconceivable that such a field device could be devised to put sensors in your home, sensors that you carry on your belt like people carry cell phones and pagers.

[52] See *Out of the Box and Into the Future Conference Proceedings*.

[53] *Ibid*.

antibiotics or vaccines. So, the right antibiotic or vaccine for the disease in use must be stockpiled. But eventually, advancements in therapeutics may allow authorities to develop and administer prophylactic medicines and vaccines to the affected population before symptoms start to present (within the period of latency of the disease). Specific bacteriophages might be useful in treating leading bacterial weapon agents, minimizing the societal impact of one or more of the leading threat agents. These "phages" can be made available, but DoD will probably have to pay for their development, which must include delivery systems.

8. Decontamination. If we had agent-specific decontaminants, we could lower challenge levels for entry into affected buildings and use of affected equipment. As a follow through, sensors must be available that can determine and provide proof that decontamination has been effective.

9. Forensics and Deterrence. Given effective sensors, both the biological agents and the perpetrators could be uniquely determined. Retribution could then follow. Improved deterrence will arise from increased uncertainties faced by potential perpetrators. For instance, we can raise a perpetrator's uncertainty through better forensics, e.g., by producing clever ways to obtain blood samples. Such steps should help in the unique determination, capture and punishment of the perpetrator. But databases must be validated and there must be a custody chain for any evidence, with acceptable transfer times and conditions, so that the pathogens do not change en route.[54]

Health and Injury. Impressive strides being made in genetics, neuroscience and other medical science will lead to major breakthroughs in treating health and injury on the battlefield. Acknowledging that most deaths during war are caused by disease, how will medical breakthroughs, so prevalent in the civilian world, affect military operations? For example, would breakthroughs impact the ability to treat the wounded during the "golden hour" while recovery is still possible? In the near term, we shall undoubtedly see the development and extensive use of telemedicine, from a pervasive and wearable "911" capability with a locator, to consultation hook-ups. Eventually we will see remote treatment and even surgery. Noninvasive tools for diagnosis and treatment have already been introduced, as have automated, electronic records systems. "Spray-on" clothing that protects injuries and dispenses drugs, when needed, will become an option. Pharmacoginomics may produce "Swiss army knife" capabilities against many of the injuries and diseases faced by the combatant in the future. These systems may even run continuous tests on their host body to determine if action is needed. Genome studies and advancements in biological sciences will bring better ways to detect, diagnose, and treat disease.

[54] Secretary Harold Smith suggested that perhaps Saddam Hussein was deterred in the Gulf War from using the biological weapons he had. Hussein was identified and informed about the possible use of "overwhelming force" in retaliation. He also saw that the coalition had protective gear and could not be sure that his biological weapons would be effective. *Ibid*.

Recommendation: The DoD should continue or initiate the following thrusts to improve troop protection:

- ***Complement the geographical or terrain-based sanctuaries that no longer work well with technology-based sanctuaries, such as advanced camouflage and decoys.***
- ***Continue the development of advanced materials for lightweight ballistic protection, especially smart materials and nanotechnology, and accelerate work on active protection and advanced camouflage.***
- ***Leverage civilian research in genetics and other biomedical areas to enhance diagnosis and treatment (and patient survivability) under the most onerous conditions of war.***
- ***Improve counter-biowarfare and terrorism capabilities through the development and application of better biocomputation, biosensors, and treatment. Also improve collaboration among government and non-government agencies and local responders through formulating better policies and procedures and adopting advanced communication and computational technologies.***

C4ISR

A symbiotic relationship between man and machine will increase military advantage of the "IT-haves" in staggering, non-linear ways. Success of decision-makers will always depend on superior access to, and manipulation of, information. Modern warfare will be characterized by network-centric operations, increased speed of command, a coalescence of levels of war, and processes that will be effects-based and output oriented. Human exploitation of, and vulnerability to, IT will soar.[55] According to an Air Force Association study, potential adversaries will have access to sophisticated commercial communications systems, will be aware of U.S. dependence on information dominance, and will act accordingly through asymmetrical responses like jamming and hacking. Information operations to counter them will have to integrate deception, software, doctrine, and tactics.[56]

The conference luncheon speaker, Dennis Bushnell, suggested that by 2025 we will be immersed in a "Tele-everything" world, whether conferencing, commuting, shopping, conducting intelligence operations or, to some extent, going to war. Improvements in connectivity, bandwidth, and data manipulation will enable military organizations to reduce some of the conventional hierarchical layering. It will also produce many side benefits and change the way the warfighter organizes.

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[55] Technological advancements pose solutions for us – <u>and for potential enemies.</u> An example used by General Hughes was a $51 overhead image made available to all in the commercial market.

[56] Air Force Association, *Shortchanging the Future: Air Force Research and Development Demands Investment*, January 2000.

Of utmost importance to the warfighter is information superiority, which translates to much more than simply receiving more *data* than our enemies. The next major wave in information technology must help us to transform the expected tidal wave of data from thousands of sources into helpful *information and understanding*. This means impressive progress in processing and, especially, software. Information superiority also means exploiting our adversaries' information weaknesses, for our side of the ledger is a combination of what we know and what our enemies do not.[57] Several technology advancements will help to accomplish this during the next quarter century.[58]

Sensors will improve, proliferate, and cover more of the available information spectrum (for instance a recent DARPA program produced an explosive sniffer named "Dog's Nose"). They will also become much cheaper. An example is the family of uncooled infrared (IR) sensors, which today provide much better performance that those ten years ago, at one-sixth the cost. Lawrence Livermore Laboratory's Center for Global Security Research recently came to the conclusion that the refinement and adoption of infrared focal plane arrays, which obsolete much of our countermeasure capabilities in this part of the spectrum, will revolutionize the entire sensor measure-countermeasure race, taking functions from radar and improving counter-stealth performance considerably.[59] If nanotechnology achieves its promise, nano-electronics will enhance our ability to detect, and identify targets from greater distances with smaller, cheaper sensor systems. Through advancements in computing and software, sensor systems will also process in-situ and display their messages with clarity. They will range from huge arrays to individual collectors. Robotics will become a growing portion of the maneuver and reconnaissance force. The generation of surveillance UAVs being introduced today will soon be joined by mini-, micro-, and eventually, nano-bots. One such concept, "swarm tactics" is an example of autonomous surveillance systems that are cheap, effective and ubiquitous. We should develop this kind of capability by 2025. These sources of data and information will form hundreds of thousand of networks, constantly replenishing military databases and cross feeding among themselves to reveal a variety of perspectives on any issue or situation.

The Internet will continue its expansion during the next 25 years. Soon we will be connecting millions of systems and billions of information appliances. The military

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[57] The DSB stated the problem succinctly in a recent report, "The task force believes that achieving and sustaining information superiority, narrowly defined, will be difficult. … The path toward decision superiority begins with data collection from a wide variety of sources and involves transforming that data first into information, then knowledge, and finally the understanding that enables better combat decisions. Faster and better decisions enabling faster and better execution is the metric by which to measure information superiority. … The rapid response capability requires forces that are able to…deploy both overt and covert sensors systems, some of which are deployed before forces are committed…" *21st Century Defense Technology*, pp. iv, 13.

[58] Needed improvements in information technologies cited in a recent DSB study include: very fast computers; mobile, high-rate communications; assured navigation capability; augmented human capabilities; universal connectivity; human-matched interfaces; and trusted environments. *Ibid*., p. xii.

[59] Proceedings form the conference, *After Globalization: Future Security in a Technology Rich World*, organized by Lawrence Livermore National Laboratory's Center for Global Security Research (CGSR) in December 2000 to be published soon.

must understand how to take advantage of this, because it cannot afford to reinvent it. DoD's need for information security and assurance will remain a problem throughout this time frame.

There are many concepts emerging today to integrate, analyze, and assimilate all of this information. Faster processing will be enabled by one or more alternative technologies emerging today, such as optical, quantum, organic, or "spintropics-based" computing, or through the substitution of new materials for silicon – from gallium arsenide to materials developed through nanotechnology. Deep computing may use virtual reality techniques to recreate an entire theater of operations – alike in almost every detail to the real one – posing solutions to the major information and knowledge problem in future military operation. Through these and other technologies, powerful computer systems will be sized for officers in the field, and extensively networked to make sense of all the data coming from their battlespace. These same processors, miniaturized sufficiently to become donnable and implantable, will push the limits of human input/output. At the same time, storage and retrieval will enhance warfighters search and memory capabilities by orders of magnitude. One CD may eventually have the storage capacity of one thousand CDs, providing the warfighter with all the information needed for an entire mission. But, data validation will always remain difficult and crucial. Incorrect or misleading information, whether accidentally or intentionally provided, will cause great operational disruption and will engender distrust of the information systems being employed.

Communications will become pervasive in order to distribute this information. Advanced optics-based communication systems will provide security and bandwidth sufficient to permit transmission of large amounts of information in text, imagery, and numerics, although difficulties will continue to exist in wireless connections among mobile stations. Improved smart wave-forms on radios at all levels of operation will be developed. Wave-form hoppers that can handle numerous wave-forms, set up their own networks, and provide continuous position navigation will be available within the next ten or so years.

Software is the proverbial weak link in information systems and there are few technologies today that will make it much better, although object-oriented programming will help, through enabling software to be reused, already free of "bugs" through extensive use. Software will remain problematical until we learn to efficiently, perhaps autonomously, and rapidly create special software for specific uses. The application of neural net or artificial intelligence (AI) may aid in assessing and testing software, making it more efficient and eliminating unneeded features that only increase software vulnerability. Neural nets and AI will also promote machines that can make decisions, ultimately on a "common sense" basis. These and other software improvements, combined with ever faster processing, will eventually introduce sentient robotics into the battlespace. As these new possibilities emerge, the same software will enable warfighters to learn how to best adapt military strategies and tactics to new technologies and vice versa through experimentation, and to provide embedded training capabilities.

Finally, command and control systems must benefit from all of the capabilities discussed above, embodying them in a holistic system. Graceful degradation of performance upon losing C4ISR systems is a difficult goal, but the U.S. military's dependence on this technology area must be tempered by an ability to function without portions of it when necessary.

Recommendation: DoD should take advantage of industrial Information and Knowledge R&D and production, while developing associated systems to satisfy special military information needs, such as information security and assurance and robust wireless networks for moving platforms. Emphasis should be on applying the next generation of technology and solving the continual problems of software creation and maintenance. It is also important for the U.S. military to maintain basic operational capabilities upon the loss of C4ISR systems ("graceful degradation").

AIR & SPACE OPERATIONS

Air and space warfare are treated as an operational continuum. We have enjoyed nearly total aerospace superiority in the 1990s, but this core competency will require attention or it will erode by 2025. Lack of funding will dictate that air-breathing platforms that we now depend upon for aerospace superiority will not change during the next 25 years. For instance, a new bomber will not and should not be built in the coming decades. There will be little change in our strategic airlift force and aerial tanker business. Current stealth technologies may become vulnerable. If stealth is ineffective, our bombing accuracy will suffer in turn. Advanced materials research will contribute improvements in airframes and stealth. Smart materials may also be introduced into aircraft or missile guidance surfaces. In this case, wings and rudders would be fabricated as single structures that deform upon the introduction of an electric current, rather than a system of mechanically sliding parts.

Space systems will have vulnerabilities that must be safeguarded. Mr. Michael Vickers suggests that space war has already begun, with jamming and development efforts on anti-satellite satellites. As suggested during the Joint Experimentation futures series, "[p]rotection of space assets, including ground nodes, is likely to become a priority mission, much like air superiority is considered today."[60]

The question of whether or not there will be weapons in space is in debate. Nearly all studies examined in the Institute's Futures Metastudy felt that space warfare and weapons (perhaps manned weapons) will be introduced into space.[61] Space weapons may include kinetic energy rods and space-based lasers. Transatmospheric vehicles are a possibility, if not a probability by 2025, spurred by commercial interests.

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[60] *Joint Force After Next*, p. iii.

[61] In contradiction, the *SPACECAST* study maintained that there is only marginal need for humans in space. Air University, *Spacecast 2020,* Technical Report Volume I, Air University Air Education and Training Command Publication, June 1994. www.au.af.mil/spacecast/intro.htm.

Space assets are becoming overwhelmingly commercial and foreign. According to the Hart-Rudman study,

> The benefits to global commerce derived from space have vastly increased investment in space technology and expertise, a trend that will no doubt continue. …the number of states and groups capable of exploiting space as an environment is expanding as a result of commercialization. More than two-thirds of today's 600 satellites are foreign-owned, and of the more than 1,500 new vehicles that will be launched over the next decade, most will be internationally owned or operated by various consortia. This raises a major intelligence challenge, for as space systems proliferate, it will be more difficult to determine their capabilities and who has access to their data. … Due to the wide availability of commercial sources of space-supported information, by 2025 the United States will no longer enjoy a monopoly in Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance. It will, however, maintain a preponderant edge…[62]

"Through both technological and diplomatic means, the United States needs to guard against the possibility of 'breakout' capabilities in space or cyberspace that would endanger U.S. survival or critical interests."[63] This has significant implications for the military, for, as suggested by the Institute for Defense Analysis (IDA)-sponsored workshop on future joint warfighting, "The U.S. space lead will erode as commercial entities proliferate. The benefit of space (imagery, communications, and navigation, etc.) will be available to adversaries, and denial may prove difficult."[64]

Science and technology will be immensely applicable to the U.S. military role in air and space, for instance:

- Surveillance assets will continue to improve, from high endurance UAVs operating in the atmosphere to space-based systems. The *Spacecast 2020* study identified several technologies and systems needed. "Implementing the concept of Global View as a reality depends on three things: an integrated, on-demand information system; increased and improved sensing capabilities; and, relatively inexpensive space lift."[65]

- Space access is *the space problem*. "Innovation in space lift—the introduction of a less expensive or reusable vehicle—requires government leadership and public funding, long-term commitments to extensive research and development, continued refinement through different generations of capabilities and high priority support. Unless or until we solve the problem of expensive space lift, we can operate in space using other technologies, but only in a halting and incomplete manner. … [One study paper suggests] a

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[62] *New World Coming Supporting Research and Analysis*, pp. 53-54.
[63] *Seeking a National Strategy*, p. 9.
[64] Hurley, p. 5.
[65] *Spacecast 2020*.

system employing space-based sensors to provide continuous, in-flight deconfliction of orbital space systems without operator manipulation."[66]

- UCAVs can contribute where they are more effective and more efficient than the manned platform. For example, a UCAV armed with directed energy weapons or in the reconnaissance business does not need high servicing rates that distinguish unmanned from manned air vehicles. Other new weapons, the adaptation of a derivative commercial aircraft as a standoff weapons carrier, and the modification and production of new sea-launched platforms will increase our global attack capabilities.

- Aging aircraft requires the development of better tools to predict aircraft availability, not just airframe life, but all components and functions.[67]

The Air University's Report 2025 suggests "several trends which characterize preparation for 2025. These trends involve shifts in relative emphasis in the following areas:

- Humans will move from being 'more in the cockpit' to being 'more in the loop;'

- The medium for Air Force operations will move from the air and space toward space and air;

- Development responsibilities for critical technologies and capabilities will move from government toward industry; and

- Influence increasingly will be exerted by information more than by bombs."[68]

Recommendation: DoD should increase its emphasis on technologies that predict and prevent failure of aging systems. Work in developing and applying failure criteria, smart materials, sensors, and computational tools should be fostered.

Recommendation: DoD should leverage efforts in NASA and the private sector to develop transatmospheric vehicles.

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[66] *Ibid*.

[67] The Defense Press Service quoted, General Michael Ryan, Air Force Chief of Staff on September 29, 2000, "Our Air Force aircraft are aging out at a rate that has us very concerned." He indicated that the average age of Air Force aircraft is 22 years and, "In 15 years it will be nearly 30, even if we execute every modernization program we currently have on the fiscally-constrained books." See Garamone.

[68] Lieutenant General Jay W. Kelley, *2025: Final Report Executive Summary*, Prepared by the 2025 Support Office, Air University, August 1996. www.au.af.mil/au/2025/monographs/E-S/e-s.htm.

IV. Science & Technology

The "Out of the Box and Into the Future" conference dinner speaker, author Dr. David Brin, remarked that, "You see it in the news, in our rapidly-shifting technology, and in the very vocabulary used at sober policy gatherings [such as the Out of the Box conference]. Going through the papers we were sent in preparation for this conference, I was struck by words like *robotics, artificial intelligence, nanotechnology, radiant-energy weaponry, viral warfare* and many other turns of phrase that com straight from science fiction novels of the recent past."

In Chapters II and III, we discussed some of the expected impacts of S&T on warfighting. In this chapter we offer a summary of some of the technical reasons we feel that the six chosen S&T areas will have important effects. In order to express the magnitude of these effects, the Institute developed a concept shown schematically in Figure 6. In this figure, S&T trends are illustrated by the large, transparent arrows, labeled A, B, and C, while individual technologies and equipment derived from those scientific trends are represented by the smaller opaque arrows. Again, the extent of their influence on warfighting scenarios is schematically depicted by changes in size and shapes of the geometrical figures that appear on the future "battlefields."

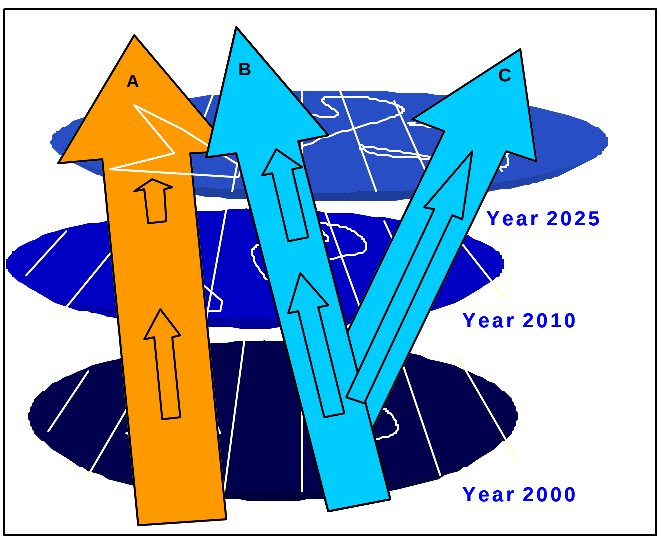


FIGURE 6. THREE CLASSES OF EFFECTS OF SCIENCE AND TECHNOLOGY: CONSISTENT, REVOLUTIONARY, AND DISRUPTIVE S&T TRENDS

Historically "Consistent S &T Trends," depicted as arrow A, will generally produce linear changes in military operations and needs. Such is the case in the ancient quest for larger, faster, and more accurate projectiles or more mobile platforms with increasing protection. Until the beginning of the second millennium, munitions generally progressed through the invention of mechanisms that permitted increased projectile throw weight, speed, or accuracy. But, "Revolutionary S&T Trends," arrow B, eventually provided more radical changes in military operations, such as:

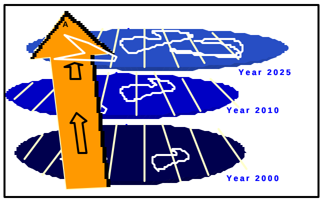
- Substitution of energetic materials for projectile kinetics;
- Attainment of extreme accuracy through guidance;
- Kill effectiveness gains through WMD warheads;
- Beam weapons that radically affect projectile throw weight and speed; and
- Personal navigation and C2I systems.

Another aim is to identify scientific trends that may be bifurcating into directions that could affect weapons, tactics, and strategies in unexpected ways. Such "Disruptive S&T Trends," depicted by arrow C, often occur as a result of what E.O. Wilson has called "consilience," the confluence of two or more scientific disciplines.[69] For example, current biomedical trends are expected to produce more deadly biological warfare agents in the future. At the same time, computer and communications sciences will deliver robotics on the battlefield. These visions exist in current forecasts. But, perhaps gene-alteration and cloning will produce biological robots. These "biobots," coupled with computer chips and amalgamated into platforms and weapons systems, could present a radical change in warfare not currently anticipated. We have classified each science and technology area treated in this project in the context of Figure 6. Naturally, this is a qualitative process, but in each case we explain our judgments. It is important to note that these assessments of impact are the Institute's opinion.

Although we tried to avoid it, there is some repetition between this chapter and those dedicated to military operations. This is true because the conclusions from the each area of S&T will sometimes "show up" under those military operational parameters that are affected.

[69] See E.O. Wilson, *Consilience: The Unity of Knowledge* (New York: Alfred Knopf, Inc. 1998).

ENERGY



Energy research will have a Consistent effect on military operations. Energy sources will become better and smaller, but will not likely radically change during the next 25 years. The one exception may be in DARPA's energy harvesting work, which could produce dramatic results. The real change will come from the new capabilities that energy source improvements will enable. Clearly, few revolutionary technologies will find application if they cannot be powered. So, while the solutions produced through energy research may not affect our forces dramatically for the next 25 years, in the longer term this research is crucial to increase efficiencies, to develop alternative fuels, and to find new ways to convert energy into usable work.

Global Energy Prospects. Our dependence on fossil fuels will continue for the next twenty years.[70] Oil and natural gas will become more expensive, while coal will remain cheap. There will be a growing reliance on Middle East oil, although some indications point to a shift to West Africa and the Atlantic Basin.[71] Non-OPEC countries, with 25% of the world's oil, are currently producing 60% of the world's crude. So, OPEC will have an increasingly larger portion of the world's reserve. New sources of oil (e.g., tar sands and heavy oil) are very expensive to extract, but renewables and more efficient end-use technologies will eventually penetrate the marketplace when economically viable.[72]

These projections, along with predicted global consumption increases, illustrated in Figure 7, means that competition over oil and natural gas will increase. Global predictions show that British Thermal Unit (BTU) consumption from oil will double during the next 20 years. East Asia will be especially impacted.[73] For instance, China will probably increase its use of vehicles by four times per capita over current use, which means ten million new vehicles. That will be accompanied by similarly greater electricity demands.[74]

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[70] According to Dr. Terry Surles, in 2020, fossil fuels will still generate about 85 percent of the energy we use. See *Out of the Box and Into the Future Conference Proceedings.*

[71] See National Intelligence Council, *Global Trends 2015: A Dialogue About the Future with Nongovernmental Experts*, December 2000.

[72] "Many scientists hold faith in nuclear fusion, or in a hydrogen-based energy economy. Some believe that energy may one day be mined from the vacuum of space—zero-point energy…[But] Even if a major innovation does come from the laboratory, it will take most of a 25-year period to create the supportive production, transportation, and marketing infrastructures necessary to make a major difference on a global scale." Major advances in efficiency, batteries, and fuel cells are likely. "As the economies of many advanced countries become more knowledge-based, and as telecommuting, telemarketing, and e-commerce become more prevalent, energy consumption patterns may change for the better, as well. American dependence on foreign sources [of fossil fuels] will also grow over most of the next quarter century." *New World Coming Supporting Research and Analysis*, p. 9.

[73] "Asia's energy consumption will likely increase over 250 percent between 1996 and 2020." *Ibid*, p. 27.

[74] "The United States must strive to reduce its dependence on foreign sources of fossil fuel energy that leaves this country and its allies vulnerable to economic pressures and political blackmail." Solutions cited include alternative sources of energy production, greater efficiencies and conservation. *Seeking a National Strategy*, p. 9.

U.S. Consumption by Fuel Type 1970-2020 (Quadrillion BTU) | **World Energy Consumption by Fuel Type, 1970-2020 (Quadrillion BTU)**

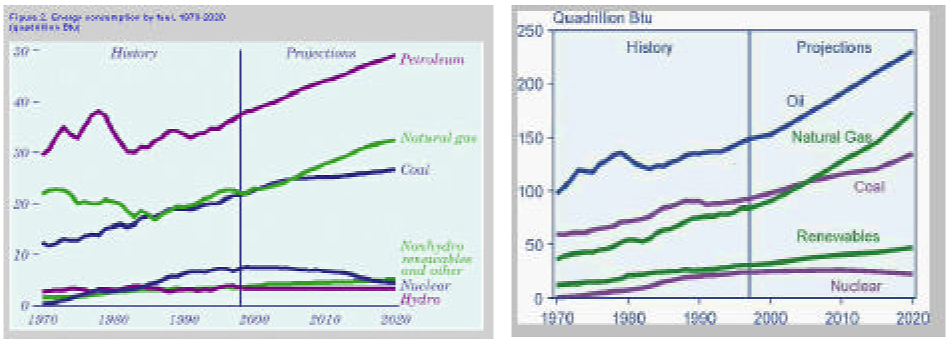

FIGURE 7. PROJECTED ENERGY CONSUMPTION[75]

Energy Solutions for Military Operations. The alternative energy conversion/transmission effort in the Army will involve hybrid power systems, fuel cells, photovoltaic cells, batteries, and even nuclear and microwave power transmission.[76] Of these, the prospects of hybrid systems look earliest, followed by fuel cells, with niche applications for photovoltaic and microwave transmission technologies.

Alternative fuels, such as hydrogen, natural gas and hydrates, synthetic hydrocarbons, and exotics (e.g., aluminum water) each have strengths and weaknesses, as indicated in Table 4. For instance, hydrogen is the most commonly cited replacement for fossil fuels, but while it has excellent energy/mass density ratio, its volumetric storage problem is severe. Energy storage requirements are summarized in Figure 8, below. There are both obvious and more subtle tradeoffs to be made.

[75] Courtesy of Dr. Terry Surles, Lawrence Livermore National Laboratory. See *Out of the Box and Into the Future Conference Proceedings.*

[76] Batteries can yield about 200 watt-hours per kilogram without suffering from rate-sensitivity. The Army wants up to 1,600 watt-hours per kilogram. Batteries deliver reasonable power, but are energy-limited.

Hydrogen:

- High Energy Content Per Unit Mass (> 3x Diesel Fuel)
- Plentiful Supply In Compounded Form
- Clean Easy Combustion
- Ultimate Fuel For Fuel Cells
- But volumetric Storage Problem (Needs Very Fundamental Breakthrough)

Natural Gas, Hydrates:

- Much More Abundant Than Petroleum Based Fuels
- High Energy Content Per Unit Mass (Not As Good As H_2)
- Clean Easy Combustion
- But Volumetric Storage Problem (Not As Bad As H_2)

Synthetic Hydrocarbons:

- Unlimited Supply From Raw Material Standpoint
- Easy Substitute For Petroleum Based Fuels
- But Production Costs Are High

Exotics: Potential For Some Improvement In Energy Density But Inherently Very Costly, Conversion (Engine) Technology Path Not Compatible

TABLE 4. ALTERNATIVE FUELS [77]

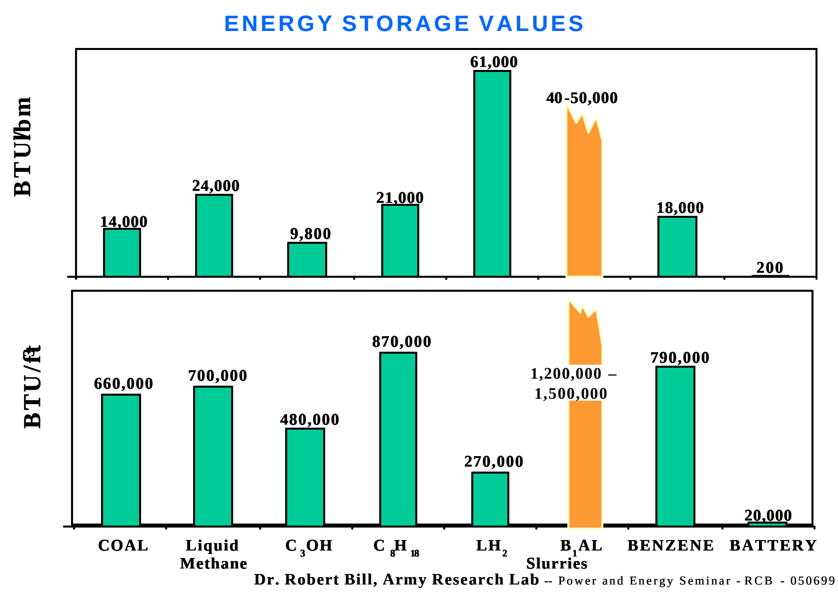

FIGURE 8. ENERGY STORAGE CAPABILITIES[78]

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[77] Courtesy of Dr. Robert Bill, Army Research Laboratory (ARL), *Out of the Box and Into the Future Conference Proceedings.*

[78] *Ibid.*

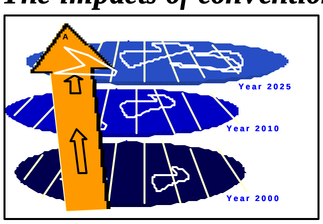
Increasingly, battlespaces are proliferating the tools of the Revolution in Military Affairs (RMA) – laptops, cell phones, and radios. But power sources remain essentially the same.[79] Needed is a half-pound energy source with half the energy density of diesel fuel, and a conversion of that diesel fuel to electricity at 50% efficiency. This is an impressive requirement that batteries or solar collectors are not likely to meet. But, perhaps innovative energy conversion systems will. The electro-chemical route can approach 100% efficiency and devices are available today for some uses. Hydrogen is the most likely fuel for the near-term, but there are several hydrocarbons, such as methane that also offer potential. Another approach is heat engines that gain efficiency through waste recycling technologies.

Direct methanol fuel cells run on a liquid fuel. The water is recirculated to reduce the logistical burden of supplying immense amounts of that component. A gallon of methanol will produce 5,000 watts of electricity and methanol is cheap. There are also some innovative ideas on how to generate the methanol. Direct conversion of hydrocarbon fuels offers extremely exciting opportunities for the future because hydrocarbons will yield 13,200 watt hours per kilogram. With large systems, and using cogeneration, efficiencies of 86% are possible.

Small, Unconventional Power Sources. DARPA's energy-harvesting program, managed by Dr. Robert Nowak, is truly "out of the box." This program is investigating raw energy sources, such as tree sap, bio-fuel cells (directly from the blood stream), heel strikes, or buoys and "synthetic eels," which are moved and excited by ocean currents to produce energy.

Recommendation: Applications of new sources and power conversion of energy from the civilian world should be leveraged by the DoD. The energy harvesting program sponsored by DARPA, an exciting example of how energy needs may be met through tapping new sources, should be fully supported.

ADVANCED MATERIALS



The impacts of conventional materials on military operations during the next 25 years are expected to be fairly linear, as opposed to providing quantum leaps in capabilities. However, it is important to maintain a reasonable level of government support, especially since conventional materials departments in academia appear to be on the wane. In the face of materials advancements, distinctions between structural and functional materials, and that between materials and devices, are blurring. Perhaps in no other scientific discipline have the fundamental building blocks changed in context as dramatically. As a result of these changes, Dr. Steven Wax proposes that material science is becoming

[79] During the Advanced Materials Panel session, Dr. George Whitesides observed that, "Energy is the Achilles heel of the RMA." *Ibid.*

increasingly interdisciplinary, employing chemistry, biology, and mathematics. People tend think about materials traditionally, "this is a composite, or a metal, or a ceramic," or "I will use that ceramic for armor." But we can no longer approach materials that way. The panel presented numerous examples that reinforce this idea, which also leads scientists and engineers to design materials for particular applications, rather than taking a material off the shelf and asking, "I wonder what this ceramic can do?"

Having said this, we decided to organize our reporting on the advanced materials session, by dividing what the panel created – a holistic approach to materials – even though the panel's approach is a more accurate picture of what is happening today. We distinguished among the impact of advancements in "conventional materials" (both structural and electronic), "materials micro devices" [e. g., microelectronic mechanical systems and nanotechnologies] and "special materials" (e.g., smart materials, uranium, explosives and propellants, and optical materials). We chose to discuss electronics materials implications under the Information and Knowledge Panel Session, materials micro devices under the Nanotechnologies Panel Session, and several problems in continuing materials development and acquisition in Chapter IV.

Unfortunately, "special materials" were not extensively discussed during the two days, but they are important and should be given attention. Smart materials have been around for twenty or so years, but we have not applied them creatively. There are several varieties of smart materials. "Shape memory materials, such as Nitinol, a family of titanium/nickel alloys, return to an original shape when heated. Piezoelectric materials expand or contract when an electrical current is applied, or conversely, generate an electrical charge when deformed. Electrorheological and magnetorheological fluids change viscosity under an electric current or a magnetic field, respectively. A smart composite can be made by embedding optical fibers in a material medium, such as concrete. The fibers transmit indications of strain. Near the material's failure point, the fibers will provide evidence that they have been fractured or broken. Another class of special materials is related to explosives and propellants. These classes of materials could have an important effect on the future battlefield, and should be addressed in a classified environment.

Conventional Materials. This is the classical venue that has dominated advanced materials research for hundreds of years, before the materials community broadened to cover a growing spectrum of development and application. Things are not over in improving conventional structural materials, but those improvements, through new alloys, better composites, and fabrication processes have slowed considerably.[80]

[80] Although, there are important exceptions. Dr. Whitesides provided an example of how conventional materials can make a big difference quickly. Giant magnetoresistive materials (GMR) went from the university adventurer to a successful, commercial technology in about ten years. This technology completely displaces the existing technology for magnetic memory in hard disks and it did that in less than a decade. On the other hand, silicon has been around for 20 years now, and we're just beginning to make progress; bucky tubes had been around for about that period of time and there are really no commercial applications; diamond film has proven to be hard to commercialize; and alternatives to silicon, such as gallium arsenide, have seen little application. See *Out of the Box and Into the Future Conference Proceedings.*

Multifunctionality, biomimicry, fabrication, and innovative application are at the root of many of the advancements expected in the future in this class of materials.

Today's weapons platforms are astounding. Seventy ton tanks gallop across the battlefield at 40 miles per hour and bombers, virtually invisible to radar, are equipped with bombs of such effect and unerring accuracy that we can afford to fly sorties of thousands of miles. But, these are evolutionary products that would be quite recognizable to the World War II soldier, except for their magnificent performance, complexity, and cost. In her presentation, Professor Merrilea Mayo asked if it is not time to start over with more advanced, but simpler systems that avoid the built-in complexities we see in older systems. Maybe, as good as these legacy systems are today, it is time to consider more elegant, multifunctional approaches, such as those discussed below.

Biomemetics is an ancient approach to design. Throughout the ages, thinkers have considered the way birds fly and whales communicate. Now, our technologies allow us to use this knowledge to gain nature's efficiencies. It is often wrong to try to copy nature's methods too closely because nature has some limitations we want to avoid. But the panel showed examples where nature could make a profound difference.

- One example was borrowed from a DARPA zoologist, who has a program to control bees and insects to accomplish simples tasks.
- Another program features a beetle that reproduces in burnt wood, requiring the insect to find forest fires up to 60 miles away and then to determine when the wood has cooled down. That requires a sensitivity of .003 degree Celsius, *using a room temperature infrared sensor* – a pretty impressive device.
- Finally, a gecko climbs walls using a million or so setas in contact with the wall to exert Van der Waals forces. A robot has been developed that uses a dry adhesive to accomplish this.

An inspiration derived from nature is multi-function. An effective and transportable 20-ton tank can only be realized by getting rid of structure. One of the ways to do this is to put function inside the structure so that the function and the structure are the same. Examples presented by the panel include:

- Structural armor using advanced ceramics, biomemetic designs, and "special" materials;
- Using the battery of a power source to support the load;
- Developing structures that are eliminated as they deliver energy;
- A windshield that also serves as an antenna;
- A battery with its own built-in battery charger and "nuclear generator;"
- Parts produced in solid free form using techniques, such as powder metallurgy, automated and coupled with computer-aided design (CAD) files for the parts data – very high precision structures can be made in-situ, rather than transporting a huge stock of parts; and

- Satisfying water needs by removing water from vehicle exhausts.

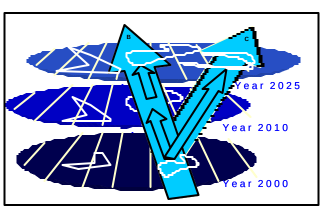
Superconductivity at room temperature has been a dream for materials scientists for years. Whether or not it will actually be put into practice remains to be seen. If it happens its impacts will be profound. In their excellent book, Marvin Cetron and Owen Davies quantify some of the motivation for superconductivity.

> In any given year, the world's generating plants churn out over 12 trillion kilowatt-hours of electricity, enough to give an average American home its standard 100-amp service for the next 125 million years. Just under one-fourth of that is produced in the United States. In this country alone, that means operating more than 100 nuclear power plants, burning nearly 170 billion barrels of oil and 100 million tons of coal per year, and routing the nation's rivers through 3,362 hydroelectric dams. And of all that electricity, produced through vast effort, investment, and environmental sacrifice, nearly one-third simply disappears. It is not wasted, exactly. It goes to overcome the electrical resistance of long-distance transmission lines, appliance cords, and the windings of electric motors.[81]

The development of better superconducting *materials* are implicit to superconductivity. Superconductivity also solves many military problems, such as enabling electromagnetic guns, faster computers, and longer lasting power sources. A basic challenge is to form usable wires and other current carrying devices from ceramics, which normally have poor tensile strength, and maintain them at sufficiently low operating temperatures.

Recommendation: Advanced conventional materials that should receive special emphasis in the DoD are smart materials, biomimicry, and superconductivity.

NANOTECHNOLOGIES



While Microelectronic Mechanical Systems (MEMS) are a Revolutionary S&T trend, nanotechnology may well be Disruptive. If nanotechnology lives up to its promises (and the jury is still out) biomedical and electronic applications already identified will likely have an overwhelming impact on military operations. Perhaps more important, however, are those military roles we cannot yet predict. This is especially true if the products of research in bio-medicine, information and knowledge, and nanotechnology are

[81] Marvin Cetron and Owen Davies, *Probable Tomorrows: How Science and Technology will Transform our Lives in the Next Twenty Years* (New York: St. Martins Press, 1997), p. 65. The authors also suggest that electric motors, which use about 60 percent of the power generated in the U.S., could be reduced in size by one-half. Cumulative efficiency savings would reduce electricity usage by 1 million kilowatt-hours per year.

combined.[82] But these military capabilities will be mere by-products of radically changed civilian lifestyles and market, because of the growth potential of this technology in the commercial sector.[83] This is a high risk/high payoff opportunity that warrants more DoD funding and attention, which should be coordinated with efforts by the NSF and NIH.

The Hart-Rudman report said it well. "[In prior times] efficiency and status lay in large scale. Now, however, miniaturization, adaptability, and speed are primary traits. … The most striking innovations in the next quarter century will occur in…information technology, biotechnology, and MEMS. … Conventional weapons systems will be characterized by an increasing emphasis on speed, stealth, lethality, accuracy, range, and networked operations. The era of Industrial Age platforms operating with impunity in the open may become outdated, as long-range precision capabilities proliferate in all dimensions of warfare (air, sea, and land)." [84] This panel's deliberations are reported under two headings, nanotechnology and MEMs.

Nanotechnology. Advances in nanoscale science and engineering may revolutionize the 21st Century in the same way that the transistor and the Internet led us into a knowledge economy. Nanotechnology is often referred to as the equivalent of the industrial revolution, and it may well be. This scientific and technology thrust could lead to molecular computers that can store the contents of the Library of Congress in a device the size of a sugar cube (equivalent to about a billion Pentiums in parallel). New materials from nano-science may have many times the strength-to-weight ratio of steel, plus very unique and useful electrical and thermal properties. The confluence of nano-technology and biology could catapult modern medicine into a new era. The best example of nanotechnology is the technology of life, represented in all the machinery of living cells. Every cell in every living thing is a little bag of water packed with nanomachines – generally enzymes, each one of which is precise down to the last atom. In many cases, these nanomachines have been optimized over billions of years to the point that they could not do their function any better. It remains to be seen if man can duplicate some of these processes over the next 25 years, for instance, electro-chemical-mechanical machines constructed on a molecular level to serve as anti-pathogens or vaccines. Even more intriguing is the possibility of creating new roles for micro entities, such as performing incredibly precise surgery.

Since the first spherical molecule with sixty carbon atoms, C_{60}, was created in a laboratory, there have been tubes, helices, and other shapes, produced by varying the

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[82] "The implications of nanotechnology are particularly revolutionary given that such technologies will operate at the intersection of information technologies and biotechnologies. This merging of technologies will produce smaller, more stable, cheaper circuitry that can be embedded and *functionally interconnected*, into practically anything – including organic life forms." *New World Coming Supporting Research and Analysis*, p. 8.

[83] Microminiaturization of computer chips and nanotechnology, coupled with artificial intelligence, will revolutionize product development and greatly expand the use of robotics in daily life. Air University, *Spacecast 2020: The World of 2020 and Alternative Futures*, Air University Air Education and Training Command Publication, June 1994.

[84] *New World Coming Supporting Research and Analysis*, pp. 6, 49.

number of carbon atoms per molecule.[85] Today, the root of the usefulness of nanotechnology is the ability to produce sufficiently large structures in sufficient quantity and quality to be effective.

Among the promise of things to come in manufacturing are self-replicating systems. Self-replication could be accomplished, for instance, through a conceptual device that its inventor, Dr. K. Eric Drexler, called a "replicator."[86] Replicators would be programmed to make copies of any nanomachine prototype desired – and to continue to make them until stopped. A conceptual example is *gray-goo*, a self-replicating dust particle that soaks up sunlight and eventually blocks out the sun over a region. Commonly expressed concerns about self-replication aspects of nanotechnologies are: 1) it cannot be done, or 2) it can be done and will be uncontrollable. The Foresight Institute has developed a version of the Foresight Guidelines to deal with issues associated with safely developing self-replicating systems.

Carbon Nanotubes. Dr. Richard Smalley discussed fullerene nanotubes, perhaps the strongest material possible. Carbon-based, it is expected to possess a tensile strength in the longitudinal direction a hundred times that of steel, and a mass one-sixth that of steel. The material is also predicted to have unprecedented toughness, high temperature resistance, and unique electro-magnetic properties that may prove very useful. Once this material is growing, one can also create a pure material made of boron and nitrogen – boron nitride. The boron nitride tube will be nearly the strength of carbon, but, unlike the carbon, it will serve as an electrical insulator. If it is done perfectly, this material would also be as transparent as quartz. Both the carbon versions and the boron nitride versions will be tremendously good thermal conductors along the longitudinal direction, but terrible thermal conductors perpendicular to this axis.

This material has been made in tiny amounts where the total number of tubes running along one another is somewhere between a hundred and a thousand, and in lengths on the order of a hundred microns. Researchers at Rice University claim they have developed a new way of making nanotubes that may be the foundation of a large-scale industrial process. They believe this technology can be used to make the material at extremely low cost – maybe as little as a dollar a pound in bulk amounts. But, commercial production at large scale is primarily dependent on finding uses and a market for the material, and that may take between one and five years.

Biomedical Applications of Nanotechnologies. Artificial biomolecules, similar to proteins and nucleic acids could be built to perform specific functions. Examples are photosynthesis, to supply power for other nanomachines; enzymes, to conduct chemical reactions; and antibodies, to identify and mark other molecules. Protein computers could become a reality – and perhaps they could be programmed to

[85] In fact, as reported by Cetron and Davies, scientists have found the spherical molecule, dubbed "buckyballs," in nature in the form of soot. They are commonly produced in laboratories by vaporizing an ordinary carbon rod with a cheap arc welder. Cetron, pp. 77-79.

[86] It was brought out in the panel session that self-replication is accomplished by systems that inhabit a wide spectrum of complexity, such as mycoplasma gentailia at 1.2 megabits and human reproductive systems at 6.4 gigabits.

reproduce. Unfortunately, the dramatically radical possibilities associated with using nanotechnologies as "micromachines" for medical diagnosis and treatment received only casual mention during the conference. There is ample discussion in the literature to illustrate how important this most revolutionary application is for chemotherapy without drugs, wound repair, tumor extraction, and other exciting prospects. These are probably the most futuristic applications to be considered – not likely to become a reality during the next 25 years, but it is worth speculating on the solutions it will offer the warfighter when it does.

MEMs. Microelectronic Mechanical Systems are still in their infancy, although unlike its more ambitious smaller sister, nanotechnologies, it is already being employed in electronic, biological, chemical, and mechanical roles. As systems become smaller and more portable and embedded, they move closer to the physical world. As that happens, one begins to effectively interact with that physical world, in a multiple set of energy domains – mechanical, electromagnetic, chemical, biological, and optical.

MEMs will introduce new ways of doing what we do better and cheaper. In addition, there is a chance that it might revolutionize warfare through new concepts, such as "Swarm" that are enabled by the size and low cost of MEMs components. As brought out by Dr. Ken Gabriel, the principal characteristic of MEMs is not size, but rather an approach to fabrication. MEMs fabrication is key to its usefulness and affordability because it enables one to build both mechanical and electrical components with materials and processes that have been traditionally used to build only electrical components. This merger provides capabilities that not only perceive but control the physical world.

Applications for MEMs include: inertial measurement units on a chip; distributed unattended sensors; integrated fluidic systems; and mass storage devices. Dr. Paul McWhorter stated that, after 15 years of development and investment, there are still relatively few commercial applications on the market at this time. Hopefully, the next generation of MEMs, fabricated through very large-scale integration (VLSI), the next step in fabrication capability, may change this picture.[87] VLSI will enable increased function distribution to enhance the capabilities of any one component, function integration from a multitude of components, and control and modulation of relatively larger forces. These extensions of MEMs will happen during the next ten to fifteen years. Cohesive industry standards for MEMs fabrication, along with venture capitalist investments should also improve their market insertion. Meanwhile, MEMs design work and prototyping continues to grow. For example, Sandia National Laboratory increased its fabrication of MEMs prototypes from tens of designs in 1993 to 1,100 in 1999, and has licensed its technology to three major U.S. semiconductor manufacturers, while negotiating another ten agreements.

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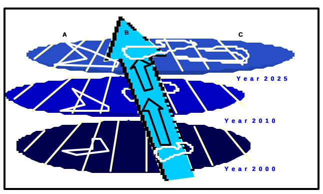
[87] According to Dr. McWhorter, "At the point that your technology development begins demanding assembly, the operation begins to become serial and expensive." An example of cost savings over conventional approaches to fabrication is a device built by Sandia National Laboratory for nuclear weapons that cost $10,000, using conventional fabrication and about $1 using MEMs technologies. See *Out of the Box and Into the Future Conference Proceedings.*

In order to get these structures down to the scale of VLSI electro-mechanics and make them easier and faster to build and test, we need higher levels of integration of electromechanical components. Also needed are robust and reliable fabrication sequences that will provide the turnaround and the reliability and repeatability of the structures as we build them.

Recommendation: The DoD should treat nanotechnology as a high-risk area, with the potential for extremely high pay-off because of the immense performance enhancements possible over a wide range of applications (e.g., structural, electronic, and medical components and systems).

HUMAN FACTORS / NEUROSCIENCE



As we develop a better understanding of the brain, neuroscience and human behavior impacts on military operations (particularly on education and training) will be revolutionary. But these changes are also difficult to predict because they are subject to so many "ifs" – if precision drugs are developed, if education and training can be made more effective, if memory can be improved, if short-term performance can be improved chemically, if all of these things can be accomplished without extreme side-effects, if policy allows their use. Whatever the potential for good and evil, the panel's observation that at least some of these things will happen and their impacts will be massive, seems reasonable. In this case, the relatively small current investment in this field may well be shortsighted.

Dr. Dennis McBride and Dr. Dan Alkon discussed the inevitable improvement in pharmaceutical technology. Drugs will become increasingly custom-tailored and tactically useful (for performance and even mood enhancement, prophylaxis, and tissue rescue). Drug science will temporarily embolden the warfighter or make the intelligence and planning staff more aware. Profound policy issues are obvious in this domain. If our knowledge about their molecular targets is specific enough, we should be able to design drugs and manipulate cognitive performance in very positive ways. [88]

In another quarter century, education will be half empirical and half scientific in the manner of medicine today, rather than mostly empirical. Dr. William Calvin predicts that we will not only know more about what works, but we'll know why it works and where it happens in the brain. We will know when to rehearse, when to present new

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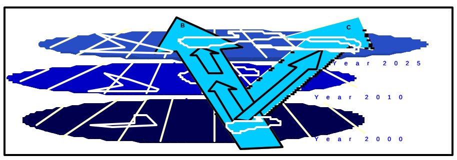
[88] Of course there is an extremely dark side to all of this. It is addressed in the Hart-Rudman study. "Our understanding of all human social arrangements is based, ultimately, on an understanding of human nature. If that nature becomes subject to significant alteration though human artifice, then all such arrangements are thrown into doubt. It almost goes without saying, too, that to delve into such matters raises the deepest of ethical issues: Can humanity trust itself with such capabilities? Should it? How can we know before the fact? Who gets to decide?" *New World Coming Supporting Research and Analysis*, pp. 20-21.

material, when to play around, and how to consolidate progress. This will change everything. We'll look the same as newborns, but as adults we will be far more capable.

Work in this area can manifest itself in at least two ways. First, warrior's capabilities could be modified through fundamentally improved education and through drugs that temporarily enhance performance. Second, to address a point made during the "Out of the Box and Into the Future" conference by Dr. David Brin, one could modify people or their actions to avoid conflict altogether, again through advanced education and even diet or drugs.[89]

BIOMEDICAL



The impacts of biomedicine on military operations will be disruptive in treating disease and injury in battlespaces and in preventing or mitigating biological attack. This area warrants more DoD collaboration with other government funding agencies, such as NIH, industry and academia.

Perhaps Dr. Claire Fraser said it best on behalf of the panel (or all scientist/technologists), "I'm reluctant to speculate these days any more than two or three years into the future given how fast things are changing." As evidence of the speed of change, she spent the first day of the "Out of the Box and Into the Future" conference among those celebrating the announcement of the completion of a human genome in the oval office of the White House.

Biological Agents. Technologies brought to bear will be developed in the civilian sector, but with a large amount of funding from government agencies, such as NIH and DoD. An example of the synergy between civilian and military needs is the challenge of mitigating the spread of disease, whether it occurs as a result of a growing population and increased global travel or to the dissemination of biological agents.

As suggested earlier, genetics may be an answer to classification. Once a completed genome sequence is in hand, one has all of the genes in a particular species.[90] In the experience of genetics researchers, whenever pathogens or non-pathogens are examined, there has always been some biology revealed by whole genome sequence information that was not even inferred or suggested before the start of genome sequencing projects.

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[89] Of course, this can lead to profound philosophical and policy questions. For instance, if Dr. Dennis McBride is correct, that war is basically a male pursuit, the antidote to conflict may be interpreted as ridding society of significant characteristics of "maleness." See *Out of the Box and Into the Future Conference Proceedings*.

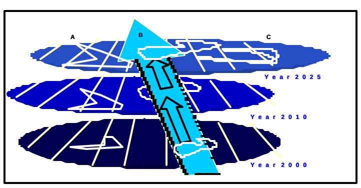
[90] The complexity and computational challenge of gene sequencing is illustrated by analogizing a genome map to a map of the U.S. showing all states and cities. Gene sequencing "maps" would also display every residence. However, non-Chromosomal genes, which may be introduced, will generally not be included.

DARPA is working on technologies for protection from biological attack. For instance, the Agency is funding work to fill molecular disease cellular receptors by combinatorial exhaustion, since there are ultimately a limited number of shapes in use. This approach searches for commonalities between the infectious disease agents, like the virulence factors, and certain receptors that are commonly used in bacterial and viral infections to design therapeutics to treat multiple diseases through common pathways. Some researchers are contemplating genetic approaches from bacteria, and then from the human genome, particularly from macrophages and the expression genes, to look for those common elements in infectious diseases where we can target drugs and vaccines. Work in immuno-modulators and bioregulators may also pose solutions. So, in 25 years our own infectious capabilities may be altered by what we understand about the human genome, macrophages, and enhancing the immune system.

Offensive Use. As discussed in Chapter III, genome research can be used to design a super bug. Perhaps the best way to deal with this danger is to develop sufficient understanding to mitigate such an occurrence. The extent of the negative side of biomedicine will depend upon how well these technologies are turned to the production of woe, rather than its prevention or mitigation. So, we must contemplate the possibility of new bioagents that are impressively tailored, diverse, multifaceted, resilient, and lethal.

Health and Injury. The impressive strides being made in genetics, neuroscience and other medical science are discussed under the section on Protection, in Chapter III.

INFORMATION AND KNOWLEDGE



The effects of information and knowledge on defense are likely to be revolutionary, and may be disruptive when combined with other technology areas. Advancements in information and knowledge technologies have not benefited the warfighter to the degree that they should.[91] It seems clear that the technology underneath processing will change, increasing processing power, thus memory, input/output, and processing speed. Similar increases in software efficiency, Internet size and distribution, sensor pervasiveness, and communications speed and bandwidth could revolutionize military operations during the next 25 years. The private sector will perform nearly all of the next generation of research, but this research will be directed toward commercial goals. The DoD must define and fill the gaps in capabilities that will continue to exist between civilian and military IT needs.

We divided this area into remarks concerning computer hardware and processing, software, Internet, communication, and civilian lifestyle changes. Information and

[91] DoD is attempting to incorporate IT over an extremely broad area of application. This complex challenge has begun to bear significant results. It is perhaps fair to say that over the next five or ten years the military will be able to effectively use today's IT, but there is another generation of IT in the wings that will be just as revolutionary and as difficult for the DoD to ingest.

knowledge technologies and their application were discussed in nearly every session of the conference, so it is not surprising that this section of the report contains perspectives and ideas furnished from outside the panel session. Panel members provided the bulk of these contributions, however, and supplied many provocative and useful thoughts. The panel was particularly helpful in defining R&D priorities in this area. Three were suggested by Dr. Irving Wladawsky-Berger: greatly improving the way we create, use and reuse software; learning to build and use large, complex, highly reliable, and secure Internet; and developing and adopting "deep computing."

Hardware and Processing. The technology underneath processing will change. It will yield more and more processing power, increasing memory, input/output, and processing speed.[92] These increased capabilities will be needed. For instance, a Department of Energy program, the Accelerated Strategic Computing Initiative (ASCI), is intended to model the behavior of nuclear weapons over time without any nuclear tests. This demands ever-bigger computers, including one, in about three or four years, whose memory will hold twice the textual content of the Library of Congress.

We may reach an end in performance gains from silicon, or complementary metal-oxide-silicon (CMOS). This is not a sure thing because powerful solutions exist within the silicon architecture. While gallium arsenide and other materials would speed up processing considerably, substituting them in production is extremely expensive. Moreover, with new production technologies, such as X-Ray or Extreme Ultraviolet Lithography, silicon chips will become more detailed, increasing their processing speed.

Other ways to improve processing involve the adoption of a wide variety of counting systems. For instance, molecular electronics, which may be viable within the next 25 years, will compute with molecules rather than with electronic charge.

Encoding information in the nucleotides that form DNA, rather than as strings of zeros and ones, will permit a considerable expansion of available sequences and significant reduction of processing times. But, it is very difficult to set up the DNA computer for a particular problem, and it is currently unreliable. Inexpensive organic electronics may find a substantial niche during the next 25 years, resulting in truly ubiquitous processing, embedded in everything, from chairs to coats to newspapers.

Quantum computing is another way around today's architecture. If transistors in a computer circuit become sufficiently small, the strange attributes of quantum theory begin to surface. Electrons disappear and reappear and the uncertainties characteristic to working at the quantum level manifest themselves in disturbing ways. Without elaboration, quantum computing has made immense gains in credibility and may become a reality in the next quarter century. If so, its unique capabilities could revolutionize some fields of physics and encryption.

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[92] For example, Cetron and Davies suggested that within 15 years, microprocessor chips will be about 15,000 times more potent than today's, without demanding revolutionary new technologies. Cetron, pp. 6 - 16.

Optical computing is here and may well be in military operations within the next decade. These computers will work with whole arrays of information, rather than single bits, increasing speed dramatically and would function efficiently as photons carry an increasing portion of transmitted data.[93] Creation of optical backplanes is currently a problem. Optical computing would be particularly efficient for image processing – clearly a military need.

Parallel computing was considered a major pathway to gain capabilities in handling the seemingly insurmountable problem of analyzing and assimilating the mass of data received from today's network connections and proliferating sensors. But, although parallel machines are relatively easy to develop and build, the software that goes into them is not. We may not get around this problem during the next 25 years, despite the fact that, for some problems, no other approach is faster.

Deep Computing was derived from IBM's Deep Blue, and is being integrated into more and more predictive systems across the business world.[94] "Blue Gene" is an adaptation of this technology to genetics.

With options as exciting as these, funding would normally be available to conduct research for about ten years, but except for DARPA, few organizations seem to be investing in them.

Software. Dr. Jacques Gansler, Undersecretary of Defense for Acquisition, Technology, and Logistics, stated at a House Armed Services Committee this year, "[If] I were to select the most critical R&D need today … it is in the software tools and management techniques. Almost every system we develop involves the dominant use of software today. And many of the problems we face in cost and schedule impacts come from software issues."[95] This opinion is echoed in DSB studies performed in 1982, 1987, and 2000. Major problems in software today include the following:

- Most software that we deliver for the warfighter is not on time.
- Software often ends up as the weak link in the systems that we try to field. Too many systems depend on complex, poorly understood software that fail unaccountably. Yet software has become increasingly pervasive and complex. Nearly every device one buys today includes software. An electric shaver has 2500 lines of code in it and there are 7500 lines in an automobile airbag. A solution is to invest more effort during design, rather than in testing. Building object-oriented software packages that are more dependable and smarter, using more robust technology to assemble systems from reusable

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[93] Dr. Alastair McAuley of Lehigh University suggests that optical computers could be operating soon at clock speeds of ten gigahertz. *Ibid*, p. 16.

[94] Every morning the Canadian Imperial Bank of Commerce uses a supercomputer to run its portfolio through Monte Carlo simulations and calculate its capital needs. With deep computing, Southwest Airlines turns on the order of a quadrillion variables into timely schedules and saves millions of dollars on crew costs.

[95] Dr. Jacques Gansler, *Testimony to House Committee on Armed Services*, Military R&D Subcommittee on Title II RDT&E, March 1, 2000.

components as opposed to coding them line-by-line. Another concept that should be applied is self-correcting or self-adapting software.

- Each feature in a software package adds to its vulnerability. So, in general, tailoring software to specific needs and eliminating extra features is preferable to maintain security, assurance, and reliability. Unfortunately, the trend today is to accept large, poorly optimized software systems, principally because our impressive processing capabilities allows us to make this choice, and because commercial software houses are not driven toward minimalist approaches by their customers.

- Poor information assurance/computer security poses a major and growing problem.[96] There is also the concern that with the increasing amount of software being developed offshore, we will import incident-supporting algorithms through commercially procured technology, incidents that are already planted in that software. [97]

- The cost of ownership, or sustainment, averages 50 to 90% of the overall cost of software.

- We don't have enough IT workers, particularly software engineers. According to the Information Technology Association of America (ITAA), one out of twelve information technology positions will go unfilled in industry.[98]

Software must get progressively better to manage growing amounts of information, making increasingly powerful computers easier to use, and ever more complex software easier to create and maintain. Object-oriented programming with standards-based infrastructure is a large part of the solution. In a crisis, no one has time to re-architect in order to take advantage of a new technology. You must be able to snap it in and move on. And only modular systems built around open standards permit an organization to quickly take advantage of sophisticated, emerging, inexpensive technologies that can be integrated immediately into the infrastructure for new function and power.[99] Perhaps most importantly, software package gains reliability each time it is reused.

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[96] The technology dedicated to hack into computer systems has become more and more sophisticated, with less skill needed by the intruder. The Carnegie Mellon University Computer Emergency Response Team has noted an increase in yearly incidents from 6 to 8,836 since 1988 (as of October 2000). See www.cert.org/stats/cert_stats/html.

[97] There was a well-documented case several years ago concerning a Solaris variant of the UNIX Operating System, supported by a company in India.

[98] According to a study on workforce and education conducted by ITAA, "In a total U.S. IT workforce of 10 million, that shortfall means one job in every dozen will be vacant." ITAA, *Bridging the Gap: Information Technology Skills for a New Millennium,* April 10, 2000. www.itaa.org/workforce/studies/hw00execsumm.htm.

[99] For example, Los Alamos was able to add a new model of high explosives into a very large code in just a few days. Previously they estimated it would take one to two years. They were able to do that because the Blanca code is object-oriented.

The combination of immense improvements in speed and miniaturization in microprocessors and advancements in software development may finally lead to the creation of thinking, maybe "sentient," robots. AI was popular twenty years ago, until we found out how hard it was to deliver. But, during the next 25 to 50 years it may be possible for a processor to handle the vast amount of data required for ordinary human feats, such as face recognition. If this happens, robots will become manifest in our society and in our battlespaces, perhaps even generally replacing human combatants. More likely, AI will do auxiliary jobs for us, such as sorting, searching, and prioritizing the tsunamis of data crashing down on our heads daily, perhaps making some of the important decisions that must now be made by busy and inefficient people.

During the next 25 years we should continue to develop the science of simulation. The combination of data access and manipulation with big processing power opens new ways of gleaning information from data and models.

<u>Internet.</u> System architectures have advanced from handling hundreds to thousands of processors. Soon, we will be connecting millions of systems and billions of information appliances through the Internet. Dr. Wladawsky-Berger's introductory remarks described the progress of the Internet very succinctly.

> Around six years ago the Internet was still pretty much the purview of research scientists and a small cadre of users who had discovered the World Wide Web.[100] Today, according to IDC consultants, well over 300 million people are connected, along with a roughly equal number of devices. By 2003, the number of people connected will almost double to 600 million, with the number of devices connected rising to about three quarters of a billion. … Standards allowed the Internet to sweep everything before it by letting people plug into information regardless of the operating system they were running. Standards are why the Internet has spread far and wide. And the continuing emergence of standards like XML and Linux – along with the open source community – is the reason the Internet will continue to grow and thrive, and be the perfect model for every other network.[101]

<u>Communications.</u> Many of the benefits described above require enormous bandwidth, perhaps available through initiatives like the Next Generation Internet. Fiber optics, permitting ten terabits per second, and other technologies will enable this bandwidth to be reached in hard-connected systems. Optical communications are rapidly replacing wired systems. There was a suggestion from the Advanced Materials Panel that, while the last 50 years was the age of microelectronics, the next 50 will be the age of optics. But wireless connections to moving stations is likely to remain a problem for the next 25 years.

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[100] In fact, Dr. Steven Cross noted that the last DSB study on software never mentioned the World Wide Web or the revolution afforded by the Internet. See *Out of the Box and Into the Future Proceedings*.

[101] David Brin reminds us that, while people are enthusiastic about the Internet liberating minds, we tend to forget that each new medium of communication caused harm before it did good. The first effects of the printing press were not to liberate minds but to liberate extreme nationalism and religious fervor, resulting in the worst war the European continent ever saw. *Ibid*.

Civilian Lifestyle Changes. Most information and knowledge technology will come from the commercial sector. The majority will be appropriate to military needs without significant changes, but the DoD must maintain a forecasting eye on the private sector to see what it will bring to defense and how much of it will be applicable. Dr. Dennis McBride, who led the Human Factors and Neurosciences Panel, offered this vision of how information and knowledge technologies will affect the civilian world in 2025.

> Today, in the year 2000, as we know from Ray Kurzweil and others… we have Pentium 32 bit, the worldwide web is ubiquitous; we're at about one bips at 300 MHz in processing. Touch screens are becoming increasingly reliable. Face recognition is beyond 50 percent reliable and going up. E-commerce is also increasing in sophistication and quantity, as is wireless communication. Contrast 10 to 20 years from now when you're basically going to see about a trillion calculations per second supported by a $1,000 investment. What does this mean? Computers are going to be everywhere, and you're not going to ever know where they are. Chips will be embedded. They'll be part your clothes. They'll be part of the walls. It's going to be a matter of information management, and not data collection. Speech recognition will be ubiquitous, and that includes multi-way translation among languages. This may worry you on the one hand because we may become more isolated, because we won't really need to learn other cultures, at least not their languages. Orbital sensing will provide detailed maps or images of locations around the world. And by the way, why can't you then send an RPV, which is prepositioned and fielded half way around the world to do dastardly deeds?
>
> Now, by the year 2025, the thousand dollars you put into your laptop computer is going to be worth about the computational power of ten human brains. So the crossover point, laptop to human, will occur sometime between 2010 and 2025. Again, computers are going to continue to increase in their ubiquity. Speech will be by far, the greater input-output device associated with computation. Virtual presence will be the norm of the day. Visual to auditory switching will be very achievable. Deaf people will gain an advantage of taking audio and converting it into text, which they'll see in a 3D rendering perhaps out on the virtual horizon somewhere. Likewise, the blind will have the spatial world rendered in auditory, and provided to them through another channel.
>
> So in 2050, a dollar buys you the computational equivalent of a human brain. Thus, a $1,000 investment in a laptop 50 years from now will get you the computation power of a thousand interactive souls. There will be sensory implants with direct neuropaths so that perhaps your memory can be uploaded and preserved forever.[102]

In addition, the marriage of these networks and small cheap sensors will produce some civilian Swarm systems. For example, the agriculture industry could scatter thousands of low-cost, miniature sensors in fields to report on soil conditions, pest populations, climate, and the hundred and one things that affect farmers, not to mention the futures markets. Cheap cellular phones, tiny multimedia devices, and

[102] *Ibid*.

personal area networks, that are always connected and always on, will provide a constant stream of information. These advancements will likely come from the U.S., although as the Hart-Rudman Commission concluded, the rest of the world is catching up. "The U.S. will likely remain the most powerful country in the international arena over the next quarter of a century."[103] "American society is likely to remain in the forefront of the information revolution. … Nevertheless, America's relative lead in this field will likely decrease as other societies adapt to the information age."[104]

[103] "What we can predict with fair assurance is that America's overall edge in military and military-related technologies will endure for the next 25 years. This is directly related to the size of U.S. military R&D spending, which amounted to $32 billion, nearly 70 percent of military R&D investments worldwide." Taken from Frank. Killelea's *International Defense Trends and Threat Projections* briefing at the Johns Hopkins University Advanced Physics Laboratory on February 26, 1999. *New World Coming Supporting Research and Analysis*, p. 121.

[104] *Ibid*., p. 120.

V. Prioritization, Funding, and Acquisition

DoD's systems of prioritization, funding, and acquisition are poor and are greatly harming chances of maintaining superior military technology over the next 25 years. Even if the superb products of science discussed throughout this report are developed during the next quarter century, the warfighter cannot gain their benefit unless they can be funded and acquired by the DoD. Government and industry alike have overwhelmingly condemned the inefficiencies of the procedures that control or guide those actions. This condemnation has been upheld by studies too numerous to cite. Issues resulting from these inefficiencies have occupied much of the time and efforts of the Acquisition Reform Office of the Office of Secretary of Defense (OSD), the Government Accounting Office (GAO), and the Office of the Inspector General (OIG). Yet, after over fifteen years of dismay, the government's procedures remain incomprehensible and illogical to outside business and an undue burden to government workers trying to accomplish something. These problems were certainly more than an irritation during the salad days of defense, when budgets kept pace with the rising stack of Federal Acquisition Regulations. But, they are now insupportable, given the DoD's increasing reliance on a commercial industry that is simply not motivated to deal with such sublime bureaucracy.

The bright spot in all of this is that much legislation has been dedicated to reducing these burdens, for example there are new versions of DoD Directives 5000.1 and 5000.2. When put into practice, this streamlining really works. But, the procedures and philosophies developed are too often constrained to special DoD projects or contracting agents (such as those in DARPA). Until these tools proliferate to the entire DoD contracting community, efficiencies will continue to be encountered only infrequently. [105]

The DoD and Congress must improve its strategies to prioritize and fund the most important areas of science and technology. There have been numerous recommendations to aid in accomplishing this task. For example, the Defense Science Board suggested that, "An acquisition approach that recognizes changing system requirements during the development and production life-cycle provides a process to field useful [military] capabilities early while continually upgrading them to

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[105] Senator Lieberman discussed some of the progress made in streamlining the system. "Through the Federal Acquisition Streamlining Act of 1994, Congress enabled the Pentagon to work with significant regulatory relief in order to improve the efficiency of the contracting process. The result was a program that successfully implemented cost-as-an-independent-variable concept, made extensive use of commercial off-the-shelf technology and a well-designed system of incentives and sanctions that gave motivation for meeting price and performance goals. The program developed a guidance kit that converted so-called dumb bombs into precision satellite-guided smart bombs. In the end, the JDAM [Joint Direct Attack Munitions] program unit cost was reduced by over 50 percent with a savings of nearly $3 billion dollars. The JDAM, as you well know, significantly contributed to precision strike capabilities, which were so critical to our operations in Kosovo. Similar acquisition strategies are evident in more and more Pentagon programs, including for example, the Virginia class submarine. But there is more work to do. We must ensure that the acquisition process, especially in information technology systems, can move just as quickly as evolving technology is moving." *Out of the Box and Into the Future Conference Proceedings*

attain desired 'ultimate' capabilities in the longer run. Three inter-related elements can accomplish this goal: an iterative requirements process, an evolutionary acquisition process, and a modular open system approach to overall program execution."[106]

The DoD must also adopt commercial best practices wherever possible. For instance, simulation-based acquisition, coupled with e-commerce techniques, is a powerful enabler for the future. One analyst expects 17 percent of total U.S. trade to be online by 2004. So, abetted by orders-of-magnitude improvements in technology, the Internet is renewing old industries, and creating new business models for all institutions.[107]

The amount of investment that DoD should sustain in S&T has been the subject of much controversy. It also received a good deal of attention during the conference. Senator Lieberman made the point that our nation is in danger of jeopardizing the technological advantage that makes our armed forces the most formidable military the world has ever known, right at a point in history when we need it most. The Senator suggested that, "In recent years, however, there has been a systematic disinvestment in the military's future, by which I mean a decline in science and technology investments, a reduction of the technical workforce, and, I think, a neglect of our defense laboratories. My goal, one that I hold dear in my work on the Armed Services Committee and which I know so many of you in this room share, is to reverse those trends by reinvigorating the forces of innovation throughout America's military services… The case that I want to make today is that technology is the key for transforming our military into a force that will be dominant, not just today, but in the future. That will only happen if the bond between scientist and warfighter is steady and strong." [108]

Congressman Weldon discussed the budgetary aspect.

> Now, unfortunately, over the past eight years our R&D budgets have been cut by 25 percent. That's not a good sign, because we're going in the wrong direction as a nation when we should be reinforcing the seed corn of the 6.1, 6.2, and 6.3 account lines. The basic research being done in our universities, the basic and fundamental research in information technology,

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[106] *21st Century Defense Technology*, p. xii.

[107] "The entire world will be linked, so that from any stationary or mobile station it will be physically possible to send and receive near-instantaneous voice, video, and other serial electronic signals to any other station." *New World Coming Supporting Research and Analysis*, p. 7.

[108] Dr. Delores Etter, Deputy Under Secretary of Defense for Science and Technology, also addressed some of these concerns in her presentation at the *Out of the Box and Into the Future conference* in June. "You cannot put dollars into S&T today, take them out tomorrow, and assume putting the dollars back on the next day will make everything okay. Science and technology doesn't work that way. It requires programs with committed people and the kind of staffs needed to do the work. That is a commitment that we have failed to maintain. There is constant talk about the importance of science and technology, and we have a lot of support in Congress. But, whether it's working Congressional budgets or budgets in the building, it's always a constant challenge to try to figure out how to keep S&T dollars there. At less than two percent of the overall budget of each of the Services, it is a very small part of the program, and Service needs are often not covered. So, readiness issues and modernization issues often overshadow science and technology, which gets lost in the end. So, we really have to figure out how to make sure S&T continues to have the kind of funding it needs to deliver the capabilities for the future." *Out of the Box and Into the Future Conference Proceedings.*

> material sciences, and in all those other disciplines that are critically important for America in the next century, and we're cutting back that funding. In fact, we've got to realize that we must turn the corner with not just the members of Congress but with the American people about the absolute need to increase our funding for research. We also need to increase collaboration, to bring universities, researchers, and the federal government together in ways that we've not done before. It is our biggest challenge, and it is one that we in the Congress in both parties are committed to undertake.[109]

It currently takes too long for technology to get from the lab bench to the field. An average of 15 years is no longer an acceptable pace for technology transition in a world moving at Internet speed. The Air Force Association agrees:

> Desert Storm's dramatic military success owed much to systems like the E-3 Sentry Airborne Warning and Control System, E-8A Joint Surveillance Target Attack Radar System, Low Altitude Navigation and Targeting Infrared for Night, AGM-65 Maverick TV-guided air-to-ground missile, AIM-120 Advanced Medium Range Air-to-Air Missile and the F-117 stealth fighter. All of these systems were products of R&D in the 1960s, 1970s and 1980s. ... but, their technology is aging, and the threat to U.S. interests is becoming ever more complicated, leapfrogging into state-of-the-art technologies. …The F-22, to be deployed initially in 2005, depends on 1980s research into supercruise, supermaneuver, Advanced Fighter Technology Integration (including digital flight control) and 'supercockpit' research. … The Joint Strike Fighter, with a projected initial operational capability in 2008, uses 1980s research in short takeoff and landing, materials and stealth.[110]

We must attract our best people to consider military careers and our best scientists to address military questions. We should approach this in several ways. For example, we must give people challenging problems and make sure their solutions get deployed when warranted by empowering them to see those solutions through. Big organizations can be frustrating, so it is important to find a way to keep big organizational characteristics out of the way of young scientists. One step in accomplishing this is to reduce the size and complexity of the administrative systems under which they work. Outsourcing and temporary employment of private sector workers in government are surely part of the answer, but DoD must change its approach in order to fully profit from such arrangements.

It is important to remember that, regardless of how many bright people are brought into DoD's R&D community, their biggest job will be to leverage the R&D funded and performed outside of the Department. This is true because most R&D funding and performance will continue to occur in the private sector. In fact, during 1998, the latest year that R&D expenditures and performance can be statistically defined, only about 43% of research and development was funded within the U.S. The rest is being

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[109] *Ibid*.

[110] Phillip Odeen added that, "[L]egacy systems procured today will be at risk in 2010-2020." *Shortchanging the Future*, pp. 5-6.

funded and, for the most part performed, offshore.[111] And about 66 percent of that portion of the U.S. R&D investment is being made within the private sector, as opposed to the federal government. Moreover, about 50 percent of the federal research and development investment is made outside the DoD, so the DoD directly controls less than 10 percent of global R&D investments. Adding the fact that commercial technologies have increasing significance to the military creates a powerful case for developing a peerless global leveraging strategy. U.S. defense R&D should represent the best from what is available throughout the world.

But, the department has more than enough trouble leveraging our own nation's private sector. The Defense Department must develop and implement policies that allow a close collaborative relationship with academia, industry and other government departments. This will create the connections and the synergy necessary to apply the technology earlier, and more innovatively and effectively than our adversaries.[112] Most advanced military capabilities will be mere by-products of radically changed civilian lifestyles and market, and procedures must be adopted that encourage the private sector to participate in solving DoD's problems, giving them more incentive (and less pain) in the process.[113] Some of this leveraging is taking place in the form of consortia or partnerships among industry, universities, and government. Cooperative Research and Development Agreements (CRADA) have become a major mechanism to bring government and national laboratories into these partnerships, but CRADAs do not solve some of the fundamental problems of integrating government efforts into those of the private sector. For example, they have proven to be an

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[111] The NSF credits roughly 43 percent of the Organization of Economic Cooperation and Development (OECD) R&D investment to the U.S. National Science Foundation, *Science and Engineering Indicators 2000*, Volume 1, January 13, 2000, pp. 2-41.

[112] The DSB urged that, "Civilian technology in key areas that are relevant to military capabilities has outstripped DoD technology development. DoD technology is not well coupled to commercial technology advances in many areas. Globalization of industry and technology permits all nations to have access to leading defense technology and equipment, provided they have the resources to procure them and the integration capabilities to effectively absorb them." *21st Century Defense Technology*, p. 54.

[113] During the *Out of the Box and Into the Future* Conference, Senator Lieberman added, "And we need to continue to reexamine profit policies and cooperative technology programs among government, universities, and industry to make sure that we are exploiting every opportunity to create incentives, including marketplace incentives, to develop innovative systems that leverage our R&D investments. As we work to transform our military to go 'Out of the Box,' to do what is counter intuitive for a successful organization and criticize ourselves in the interest of our future national security. We're faced with some real challenges. We must ensure that innovative ideas and innovative people are encouraged and protected as we seek to move our systems and organizations into the 21st century. We must speed the process of moving ideas and technologies through the system in a more efficient and responsive way so we can field the most capable force in the future. And we must reconnect the military to the best science and technology that has brought us to where we are today. That is the only way we're going to maintain our position in the future. In the end, Congress has a critically important role to play, but so do all of you, because ultimately, to say what is self-evident, innovation is going to come, not from Congress, but from the scientists and the warfighters. …And I hope this conference serves, as it already has, to improve the communication and understanding between these two groups. I hope we will all think harder together about the future direction of warfare, what resources and policies will be needed to satisfy our national security needs in the face of a rapidly changing and remarkably uncertain world." *Out of the Box and Into the Future Conference Proceedings.*

awkward connection to industry for the national laboratories because of the legislative admonitions against competition between the public and private sector.

Since much of the military's S&T will come from the commercial sector and will be available to any customer who wants them, the DoD must develop unique tools for the U.S. warfighter and deny them to our enemies. This is a difficult challenge and it depends on our ability to be better than anyone else in: 1) finding, adopting, and adapting new commercial technologies to military use; 2) integrating these technologies into unique and innovative solutions, 3); deploying them in a way that maximizes their benefit; and 4) as much as possible, preserving them for our use, perhaps by safeguarding information on systems, rather than individual technologies.

Cost will become an even greater factor. Energy intensive defense production (of large platforms and weapons systems) will cost more in the future. It is essential that future systems be based on capabilities and cost, perhaps on an equal footing rather than on solutions to specific problems. The immense cost of equipment employed in a modern air war, such as Kosovo, is illustrated in Table 5, below. Once again, the adoption of commercial components and technologies will greatly reduce systems costs, particularly in maintaining, upgrading, and replacing fielded systems.

WEAPON SYSTEM	UNIT COST ($M)
E-3 Sentry	270
F-117A Stealth Fighter	45
F-16 Fighter	20
F-15 Fighter	43
B-52 Bomber	30
B-1 Bomber	200
B-2 Bomber	1,300
Tomahawk Cruise Missiles	1
J-STARS Aircraft	260

TABLE 5. TYPICAL COSTS OF AIR WAR EQUIPMENT[114]

There are many examples of the challenges that face the nation in nurturing important areas of S&T. One especially difficult area is Advanced Conventional Materials. The plight of research community was discussed by that panel during the conference and is summarized in the box below.

[114] ABCNews.com, *The Cost of Kosovo*, March 26, 1999. Original source of information was the U.S. Air Force. See www.abcnews.go.com/sections/world/DailyNews/kosovo_costs990326.html.

Special Concerns in Advanced Materials Development. The Advanced Materials Panel asserted that the DoD must begin now to identify requirements for materials, because of the long lead times generally entailed in a materials breakthrough. The panel also assumed that most of the materials breakthroughs will come from commercial industry, and will therefore become available to our adversaries. This is true partly because government funding for conventional materials development is decreasing and commercial industry will develop, produce, and sell a progressively larger percent of the new materials available to the DoD. There will be some interesting trade-offs among capabilities enhancements made possible by conventional materials advancements.

The panel was particularly concerned about the ability to develop and deliver advanced materials technologies to the U.S. military. Commercial off-the-shelf (COTS) technologies are most advantageous to the first military adapter, but the military must develop better ways to adopt new technologies quickly or it may forfeit this important advantage.

Most disturbing was the warning that several advanced materials fields in academia are in peril as a result of DoD funding cuts over the years (60% of all academic materials research is DoD-funded). Some materials fields may disappear (e.g., metallic structural materials, advanced materials for wireless communications). In addition, most applications discussed by the panelists (e.g., anti-stealth; chemical, biological and nuclear protection; and destruction of hardened targets) were unlikely to be developed by the commercial sector. As a result, there is a large amount of technological work to be done – and a lack of people and resources with which to do it.

A major part of the problem is that the system of inventing, developing, and commercializing materials in the United States is fundamentally broken. People are not investing in materials because the developmental lead-times are so long. We must learn the tricks for getting materials through technology development programs. The U.S. is currently well ahead of other countries in certain areas. But, we won't stay that way for long. Developments in Singapore, Korea, China, and India will close that gap very soon. Many of those countries have a knowledge base, although they are missing a manufacturing base.

Recommendation: DoD's prioritization, funding, and acquisition procedures and processes should be fundamentally reconfigured to gain efficiencies and effectiveness, to access the best scientists and technologists to address military questions, and to gain the help of a private sector that is progressively less interested in accommodating DoD's arcane acquisition practices.

Recommendation: DoD should perform most defense R&D collaboratively among all interested government agencies, academia, and commercial industry, ending the tendency to compartmentalize efforts within various departments, especially as the DoD becomes increasingly reliant on commercial technologies.

Recommendation: The DoD should innovate ways to develop unique tools for the U.S. warrior while denying them to our enemies.

Recommendation: The DoD should increase its efforts to develop and implement approaches to predict and mitigate failure of aging platform systems and to effectively and affordably upgrade those systems through technology refresh techniques.

VI. Next Steps

The following are some ideas for follow-on work that logically emerge from conclusions drawn earlier. They concern the directions to be taken in continuing the Project. These are changing as new ideas are offered.

1. Continue to collect and analyze the results of selected new futures studies. This recommendation is based on an observation that while there are quite a few futures studies and conferences, little effort is being directed toward developing wisdom across the resulting body of information – a kind of "meta-study" approach. Indeed, one of our conclusions from the "Out of the Box" Project is that there are important synergies among the fields of science, technology and warfighting that are not sufficiently well understood to exploit.
2. Choose a particular topic and focus on it in another event - a conference, wargame and/or a series of seminars. Topics of interest include: acquisition of advanced technologies for the 21st century; likely S&T influences on coalition warfare, urban warfare, or counter terrorism; or a chosen S&T area, such as nanotechnologies. Although DoD has covered some of the potential topics, we would propose to include these participants and incorporate their findings into our studies, further developing the subject. The Institute would also study the scientific community and create a forum for interaction between the warfighter and the scientist.
3. Conduct a detailed analysis of one or more issue areas that came out of the project. We are in the process of identifying candidate issues. Some of these issues are areas that the Institute has worked in. Examples are:
    a. How can DoD should change its approach toward acquiring the advanced technologies it needs? This is essentially a 21st century acquisition system study focused on R&D.
    b. How can the DoD change its requirements process to better enable adoption and adaptation of emerging science and technologies from the commercial and defense sectors?
    c. How should concerns expressed over the past year or two regarding the combination of such S&T areas as nanotechnologies, biomedical, and information and knowledge be addressed in terms of actionable policies?
    d. What will be the likely contribution of advanced materials and nanotechnologies to solving military transport problems?

APPENDIX A. CONGRESSIONAL LETTERS OF INITIATION

United States Senate

WASHINGTON, DC 20510

March 22, 2000

Michael Swetnam
Potomac Institute for Policy Studies
1600 Wilson Boulevard
Suite 1200
Arlington, VA 22209

Dear Mr. Swetnam:

We are writing in support of the upcoming conference "Out of the Box and Into the Future: A Dialogue Between Warfighters and Scientists on Far-Future Warfare (2025)" and its related events, being organized by the Potomac Institute for Policy Studies. This unique event was developed from discussions between Congress, the defense policy community, and defense research scientists in order to promote the sharing of ideas between the civilian R&D community and the uniformed military on critical issues of national defense. It is particularly exciting to note the participation of the Joint Forces Command and the Coalition for National Security Research, and the distinguished steering committee engaged in shaping the conference.

This worthwhile effort will bring together the U.S. military, the science and engineering research communities, and members of Congress to explore the impact of rapid advances in science and technology on far-future warfare. It will promote a better understanding for all parties involved of the interplay between the scientific and warfighting communities, and the critical impact of research on future military operations.

Upon conclusion of the conference and preparation of a summary report, we request a formal briefing on your recommendations and future plans. We are particularly anxious to hear your informed opinions on the scientific and technical areas that will impact future military operations and thus, require additional S&T investment from Congress and the Department of Defense, as well as recommendations on methods for improving communication between scientists and the military.

Thank you again for your excellent effort and progress thus far towards this important project.

Sincerely,

JOSEPH I. LIEBERMAN   PAT ROBERTS   JEFF BINGAMAN

Congress of the United States
House of Representatives
Washington, DC 20515

April 27, 2000

Michael Swetnam
Potomac Institute for Policy Studies
1600 Wilson Boulevard
Suite 1200
Arlington, VA 22209

Dear Mr. Swetnam

We are writing in support of the upcoming conference *Out of the Box and Into the Future: A Dialogue Between Warfighters and Scientists on Far-Future Warfare (2025)* and its related events, being organized by the Potomac Institute for Policy Studies. This unique program was developed from discussion between Congress, the defense policy community, and defense research scientists in order to promote the sharing of ideas between the civilian R&D community and the uniformed military on critical issues of national defense. It is particularly rewarding to note the participation of the Joint Forces Command, the Coalition for National Security Research, and the Potomac Institute for Policy Studies as well as the impressive steering committee engaged in shaping the conference.

We are enthused about bringing together the U.S. military, the science and engineering research communities, and members of Congress to explore the impact of rapid advances in science and technology on far-future warfare. It will promote a better understanding for all parties involved concerning the interplay between scientific and warfighting communities, and the critical impact of research and development on far-future military operations.

Upon conclusion of the conference and preparation of a summary report, we request a formal briefing for Congressional Members and senior staff on your recommendations and future plans. We are interested in further learning, and informing our colleagues about, the scientific and technical areas that will impact future military operations and thus, require additional S&T investment from Congress and the Department of Defense.

Thank you again for your excellent effort and progress thus far towards this important project.

Sincerely,

Curt Weldon
Member of Congress

Rob Andrews
Member of Congress

PRINTED ON RECYCLED PAPER

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24) Zachary, G. Pascal. "Market Forces Add Ammunition to Civil Wars—Research Suggests Rebels have 'Greed' as Motive." *The Wall Street Journal.* June 12, 200, p. A21.

Appendix C. Conference Speakers

SPEAKER	ORGANIZATION	AREA
Dr. Dan Alkon	National Institutes of Health	Human Factors/Neuroscience
General Joseph Ashy, USAF (Ret.)	Former CINC, US Space Command and NORAD	Space Warfare
Dr. Robert Bill	Army Research Laboratory	Energy
Dr. Joseph Bordogna	Deputy Director, National Science Foundation	
Dr. David Brin	Author, "The Postman" and "Earth"	Dinner Keynote
Dr. Dennis Bushnell	Chief Scientist, NASA Langley	Asymmetry
Dr. William Calvin	Affiliate Professor of Psychiatry and Behavioral Sciences at the University of Washington	Human Factors/Neuroscience
VADM Arthur Cebrowski, USN	President, Naval War College	Information/Networking
Major General George Close, USA (Ret.)	Former Director, Operational Plans and Interoperability	JV 2010
Dr. Stephen Cross	Director, Software Engineering Institute, Carnegie Mellon University	Information and Knowledge Chair
Dr. Millie Donlon	Program Manager, Special Projects Office, DARPA	Biomedical
Dr. Delores Etter	Deputy Under Secretary of Defense (Science and Technology) and Deputy Director, Defense Research, Development, and Engineering	Morning Session Keynote
Dr. Frank Fernandez	Director, DARPA	DARPA's Technology Strategies
General Ronald Fogleman, USAF (Ret.)	Former Chief of Staff of the Air Force	Air Warfare
Professor Ken Gabriel	Professor of Electrical Engineering, Carnegie Mellon University	Nanotechnologies
ADM Harold Gehman	CINC, U.S. Joint Forces Command	Conference Co-Chair
General Paul Gorman, USA (Ret.)	Former CINC, U.S. Southern Command	Firepower
General Al Gray, USMC (Ret.)	29th Marine Corps Commandant	Maneuver & Power Projection
Lieutenant General Pat Hughes, USA (Ret.)	USA (Ret.), Former Director, Defense Intelligence Agency	Threat
Dr. Stuart Kauffman	Chief Scientific Officer, Bios Group LP	Biomedical Chair
Senator Joseph Lieberman	D-CT, Senate Armed Services Committee	
Dr. Hans Mark	Director, Defense Research, Development, and Engineering	Afternoon Session Keynote

Professor Merrilea Mayo	Associate Professor Of Materials Science And Engineering, The Pennsylvania State University	Advanced Materials
Dr. Ralph Merkle	Principal Fellow, Zyvex and Former Research Scientist at Xerox Palo Alto Research Center	Nanotechnologies
Dr. Paul Messina	Director, ASCI Program and Professor of Computer Science, California Institute of Technology	Information and Knowledge
Dr. Dennis McBride	Professor of Psychology and Engineering, University of Central Florida and Director, Institute for Simulation and Training	Human Factors/Neuroscience Chair
Dr. Paul J. McWhorter	Deputy Director, SNL Microsystems Center	Nanotechnologies
Dr. Robert Nowak	Program Manager, Defense Science Office, DARPA	Energy
Ralph Peters	Author, "Fighting for the Future?"	
Dr. James Richardson	Vice President for Research, Potomac Institute for Policy Studies	
Major General Robert H. Scales, Jr., USA (Ret.)	Commandant, Army War College (since retired)	Chair, Fundamental Warfare Parameters Panel
Prof. Richard Smalley	Professor of Chemistry and Director, Center for Nanoscale Research, Rice University	Nanotechnologies Chair
Dr. Harold P. Smith, Jr.	Distinguished Visiting Scholar, Goldman School of Public Policy, University of California - Berkley	Biomedical
Dr. Terry Surles	Lawrence Livermore National Laboratory	Energy Chair
Mr. Mike Swetnam	President and Chairman, Potomac Institute for Policy Studies	
Dr. Charles Vest	President, Massachusetts Institute of Technology	Conference Co-Chair
Dr. Steve Wax	Deputy Director, Defense Science Office, DARPA	Advanced Materials
Representative Curt Weldon	R-PA, Chair, Subcommittee on Military R&D, House Armed Services Committee	Conference Co-Chair
Dr. George Whitesides	Professor of Bioorganic/Physical Organic Chemistry and Materials Science, Harvard University	Advanced Materials Chair
Dr. Patrick Winston	Ford Professor of Artificial Intelligence and Computer Science, MIT	Opening Remarks on behalf of Dr. Vest (Co-Chair)
Dr. Irving Wladawsky-Berger	PITAC Co-Chair; Vice President, Technology and Strategy-Enterprise Systems Group, IBM Corporation	Information and Knowledge

Appendix D. Acronym listing

AAN	Army After Next
AF	Air Force
AFJI	Armed Forces Journal International
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFV	Alternative Fueled Vehicles
AGM-65 Maverick	The AGM-65 Maverick is a tactical, air-to-surface guided missile designed for close air support, interdiction and defense suppression mission
AI	Artificial Intelligence
AIAA	American Institute of Aeronautics and Astronautics
AIDS	Acquired Immune Deficiency Syndrome
AIM-120	The AIM-120 is an all-weather, radar guided, air-to-air missile with launch-and-leave capability in both the beyond-visual-range and within-visual-range arenas enabling a single aircraft to engage multiple targets with multiple missiles simultaneously
ASCI	Accelerated Strategic Computing Initiative
ASEE	American Society of Engineering Education
AWAC	Airborne Warning and Control System
B-1	B-1B is a multi-role, long-range bomber, capable of flying intercontinental missions without refueling, then penetrating present and predicted sophisticated enemy defenses
B-2	B-2 Spirit is a multi-role bomber capable of delivering both conventional and nuclear munitions
B-52	B-52 is a long-range, heavy bomber that can perform a variety of missions
BTU	British Thermal Unit
C3I	Command, Control, Communications and Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAD	Computer-aided Design
CalTech	California Institute of Technology
CD	Compact disk
CERT	Computer Emergency Response Team formed at the SEI by DARPA in 1988
CERT/CC	CERT Coordination Center
CGSR	Center for Global Security Research
CINC	Commander in Chief
CINCTRANS	Commander in Chief, U.S. Transportation Command
CMOS	Complementary metal-oxide-silicon
CMU	Carnegie Mellon University
CNO	Chief of Naval Operations
CNR	Chief of Naval Research
CNSR	Coalition for National Security Research
CO_2	Carbon Dioxide
COTS	Commercial-Off-The-Shelf
CRADA	Cooperative Research and Development Agreement
DARPA	Defense Advanced Research Projects Agency

DNA	Deoxyribonucleic Acid
DoD	Department of Defense
DSB	Defense Science Board
E-3 Sentry	The E-3 Sentry is an airborne warning and control system (AWACS) aircraft that provides all-weather surveillance, command, control and
E-8A	Long-range radar reconnaissance aircraft; program name, Joint Surveillance and Target Attack Radar System (J-STARS)
EM	Electromagnetic
F-117	The F-117A Nighthawk is the world's first operational aircraft designed to exploit low-observable stealth technology
F-15	The F-15 Eagle is an all-weather, extremely maneuverable, tactical fighter designed to permit the Air Force to gain and maintain air superiority in aerial combat
F-16	F-16 Fighting Falcon is a compact, multi-role fighter aircraft
F-18	F/A-18 Hornet, an all-weather aircraft, is used as an attack aircraft as well as a fighter
F-22	The fast, agile, stealthy F-22 Raptor will take over the air superiority role with Air Combat Command starting in 2005
FCS	Future Combat System
FGCS	Future Ground Combat System
FDA	Food and Drug Administration
FY	Fiscal Year
GAO	General Accounting Office
GDP	Gross Domestic Product
GHz	Gigahertz
Global Hawk	Global Hawk is a high-altitude, long-endurance unmanned air vehicle
GMR	Giant Magnetoresistive Material
GPS	Global Positioning System
H_2	Hydrogen (Gaseous)
HPC	High-Performance Computing
ICBM	Intercontinental Ballistic Missile
IDA	Institute for Defense Analysis
IEEE	Institute of Electrical & Electronics Engineers
INS	Inertial Navigation System
IR	Infrared
ISR	Intelligence, Surveillance, Reconnaissance
IT	Information Technology
ITAA	Information Technology Association of America
JDAM	Joint Direct Attack Munitions
JFCOM	Joint Forces Command
J-ROF	Joint Rapid Response Operations Forces
JSF	Joint Strike Fighter
JSTARS; J-STARS	Joint Surveillance and Target Attack Radar System
JV2010	Joint Vision 2010
JV2020	Joint Vision 2020
Kbps	Kilo bytes per second
LIDAR	Light Detection and Ranging
LLNL	Lawrence Livermore National Laboratory
M&S	Modeling and Simulation
Mbps	Mega bits per second
MEMS	Microelectronic Mechanical Systems

MHz	Megahertz
MIT	Massachusetts Institute of Technology
mph	Miles Per Hour
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBC	Nuclear, Biological, Chemical
NGI	Next Generation Internet
NIC	National Intelligence Council
NGO	Non-governmental Organization
NIH	National Institutes of Health
NRO	National Reconnaissance Office
NSA	National Security Agency
NSF	National Science Foundation
NSSG	National Security Study Group (Hart-Rudman Commission)
OECD	Organization for Economic Cooperation and Development
OIG	Office of the Inspector General
ONR	Office of Naval Research
OPEC	Organization of Petroleum Exporting Countries
OSD	Office of the Secretary of Defense
PITAC	Presidential Information Technology Advisory Committee
R&D	Research & Development
RF	Radio Frequency
RMA	Revolution in Military Affairs
RPV	Remote Piloted Vehicles
RSOI	Reception, Staging, and Onward Movement Integration
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RUF	Revolutionary United Front
S&T	Science and Technology
SAM	Surface-to-Air Missile
SEI	Software Engineering Institute
SGI	Silicon Graphics, Inc.
SSN	Attack Submarine (Nuclear Propulsion)
TRADOC	U.S. Army Training and Doctrine Command
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Air Vehicle
UGV	Unmanned Ground Vehicle
US	United States
USA	United States Army
USAF	United States Air Force
USD (AT&L)	Under Secretary of Defense (Acquisition, Technology, and Logistics)
USJFCOM	United States Joint Forces Command
USMC	United States Marine Corps
USN	United States Navy
UUV	Unmanned Underwater Vehicle
UWB	Ultra Wide Band
VLSI	Very Large Scale Integration
VR	Virtual Reality
WMD	Weapons of Mass Destruction
WME	Weapons of Mass Effect
WWW	World Wide Web

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