Waiting for Sputnik

Basic Research and Strategic Competition

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Preface

Promoting innovation has become a mantra for policy. Frequent repetition does not make the mantra wrong – increasing a nation's capability to innovate is the best response to economic globalization and offers real benefits for security and economic growth.

Globalization integrates markets and spreads manufacturing and research capabilities among nations, creating real risks for U.S. security and economic strength. Globalization means that U.S. leadership in technology and innovation, absent any change, will erode in ways that damage its national power and the welfare of its citizens.

Many studies have laid out stark evidence showing the dimensions of the challenge. These studies also make many recommendations on how best to respond. But some recommendations face serious obstacles. Tax reform could accelerate innovation, but rewriting the tax code will be an arduous task. A more efficient health care system would reduce obstacles to entrepreneurship, but no solution is in sight. Improving primary education raises political and social issues, and the fragmented nature of the American school system (with 15,000 separate school districts) works against change.

Increased funding for basic research is another of the 'standard' recommendations for improving competitiveness and innovative capabilities. It is more attractive because it is comparatively easier to implement – Federal funding mechanisms are in place and there is support for maintaining scientific leadership. The sums involved entail about a tenth of a percent of GDP. A decision to increase funding and direct this new funding to the right research areas can be made quickly, and benefits would quickly accrue to the U.S.

Increased Federal funding for basic research plays to U.S. strengths. Basic research does not automatically produce innovation or economic growth. The process for turning the advances in science that basic research produces into economic or military advantage depends on the strength and nature of the 'innovation system' found in each country. The process is complex and is shaped by legal, financial, cultural and business conditions – sometimes called 'soft infrastructure.' In this, the U.S. has a comparative advantage. Its innovation system remains the most responsive in the world. This advantage means that the U.S. would gain more from increasing basic research than would its competitors.

The following report concludes that America is underfunding the areas of basic scientific research that are crucial for security as we face another great cycle of change produced by globalization. It lays out the strategic rationale for increased funding; identifies the research areas where shortfalls pose the greatest risk to U.S. security, and recommends a course of action for moving ahead. If there is one point that we hope you take away from *Waiting for Sputnik*, it is that the underfunding of basic research in physics, math and engineering is not a problem for science policy or business, but a major challenge for the future security of the United States.

Waiting for Sputnik: Basic Research and Strategic Competition

Executive Summary

Basic research fuels innovation; innovation produces national strength. Since the 1940s, spending on scientific research has been crucial for U.S. national security. Our investment in science and technology underpins America's current military and economic strength. The problem is that funding levels that were adequate in the past are now insufficient. A series of interconnected changes are reshaping the international environment in ways that challenge U.S leadership:

– **Globalization** has diffused technology and research capabilities around the world and helped to create the wealth that lets many countries pursue technological leadership.

– The **transition to an information economy** will make the countries that are better at creating new knowledge the economic powers of the next century.

– Few companies can invest in basic research in a **competitive international business environment** that demands results in the next quarter, not the next decade. Some analysts believe that DOD has made a similar shift away from basic research.

– **Asia's economic ascent** made that region a leader in global manufacturing. Now Asian nations hope to repeat this success in scientific research. China, India and other Asian nations are increasing their research capabilities at a faster rate than the U.S.

– **Sophisticated commercial technologies** that perform like military equipment diminish the U.S. military advantage and put a premium on accelerating research.

The U.S. is underinvesting for this new strategic environment. It spends more than other nations on research and development, but the figures hide a damaging deficiency in key areas -- basic research in physics, mathematics, computer sciences, and engineering. These scientific and engineering disciplines are the basis for military transformation, provide the workforce for sensitive projects, enable other kinds of science, and are the ultimate source of economic growth. Measured by share of GDP, their funding has decreased steadily since 1975.

Some of the consequences of underinvestment are already apparent – such as a shortage of U.S. citizen scientists to work in sensitive national security programs. Other effects – the shortfall in the research conducted at universities and other institutions that feeds economic and military innovation – will not appear for another five to ten years. The U.S. still leads, but its advantage is shrinking as our spending slows while strategic competitors accelerate their efforts.

Basic research is not a conventional national security problem, but decisions on research funding have major implications for the national interest. Technological superiority provides the U.S. with unprecedented strength and influence. It comes from a dynamic process of innovation that links the discovery of scientific knowledge to economic and military advances. The connection between basic scientific research and national

strength lies in the ability of a nation to innovate, and turn research into new products and services. The U.S. has an unparalleled ability to innovate that is the envy of other nations, but they have looked upon our success and now seek to duplicate it.

The effect of underfunding on national security is acute and damaging, but a sense of urgency is undercut by the long lag between the production of new knowledge from basic research and the transformation of this new knowledge into products and services. Research into quantum physics in the 1920s laid the foundation for a microelectronics industry that did not appear until the 1950s. Physicists began to discuss nanotechnology in the late 1950s, but products are only now appearing on the market. The research behind the Internet began in the late 1960s, years before it unleashed sustained economic growth. The long interval between basic research and benefits can create pressure to defer funding in times of budgetary constraint. Unfortunately, the U.S. has been deferring investment in key research areas for decades. The conclusion of this report is that the United States has underestimated the consequences of underfunding basic research for the new strategic environment.

Basic research, which has no immediate commercial application or use, depends on federal funding. Today's competitive environment does not allow the private sector to invest in experiments whose payoff may not appear for a decade. Federal funding will determine the scope and pace of discovery and the size of the technological workforce required to meet U.S. national security needs.

The President has identified three budget priorities: winning the global war on terrorism, defending the American homeland, and moderating increases in discretionary spending. These priorities address the risks facing the U.S. today, but the U.S. also needs to respond to the long term strategic challenge. A fourth priority must be to accelerate innovation to meet the new strategic challenge to economic growth and national security. We have four recommendations on how to do this:

1. **Restore funding** for basic research in the physical sciences and engineering across all domestic non-defense research agencies to the levels needed to meet long-term economic and national security requirements.

2. **Commit a larger proportion of Defense spending** within current Research, Development, Testing and Evaluation (RDT&E) funding levels to basic research and S&T workforce development.

3. Establish **new mechanisms for partnerships** with the private sector, other agencies and other governments (including both the state governments within the U.S. and allied governments outside) to support university research.

4. Create **new governmental funding vehicles** (such as special purpose bonds, investment incentives, or endowments) to leverage current federal allocations.

Waiting for Sputnik: Basic Research and Strategic Competition

Introduction

> "Our leadership position in science and technology is an essential element in our economic and physical security."
> Ronald Reagan, 1985

Research and development (R&D) is essential for U.S. economic strength, technological leadership and for national security. The risks from shortfall and misallocation are great. Unfortunately, there is growing evidence that America is not funding the right kinds of R&D. The underfunding of basic research in the physical sciences (such as physics, mathematics, and engineering) puts U.S strength at risk. Although the damage might not appear for years, America is not making the R&D investment decisions needed to sustain its strength and competitiveness.

This report describes why increased funding for basic research in key scientific areas is critical for security. An initial reaction to this proposal might well be, why do more? The U.S. leads the world in spending on R&D.[1] Federal funding of R&D is at a record high. But our examination shows that the U.S. is not investing in the kinds of research needed for national security.

The reasons for this lie in the changing strategic environment that America faces. A series of interrelated changes has put U.S. technological leadership at risk. Funding levels that appear more than adequate are in fact insufficient to meet these new challenges. The metaphor for increased research funding comes from a NASCAR race – the speed that put you in the lead will not keep you there when your competitors accelerate.

This is not science policy. This is an issue for national security. Just as levels of defense spending must increase in a period of heightened threat, levels of R&D funding for basic research must increase in a period of heightened global competition. Strength in science and technology is important because it is an essential ingredient for U.S. economic and military strength.

This strength is the outgrowth of a dynamic national process for innovation that connects the discovery of new scientific knowledge to economic and military activities. Basic research is the source of that new knowledge. Basic research is the fuel that powers innovation. But basic research, which has no immediate commercial application or use, is critically dependent on federal funding. Only in rare instances is basic research supported by industry which is driven by competition to make its R&D investments in

[1] R&D is systematic creative work to increase the stock of knowledge and to devise new applications using this knowledge. R&D falls into three broad categories: basic research, applied research, and development. Basic research is experimental or theoretical work, usually undertaken at universities or other research institutions, to acquire new knowledge. Applied research and development then turns this new knowledge into products and services.

shorter term applied research and product development.

The connection between basic research and national strength lies in the ability of a nation to innovate. Innovation is the development of new products, services or methods of production through the application of scientific research or invention to commercial or military activities. Innovation is particularly important once economies become mature and can no longer expand by simply increasing the supply of resources devoted to production. Instead, they must find new ways to use resources more efficiently. The U.S. has an unparalleled ability to innovate that is the envy of other nations, but they now seek, with some success, to duplicate it.

The linkages between basic research, innovation and security are not direct. It takes time to transform the production of new knowledge through basic research into products and services, and there can be long lags between discoveries in basic research and their commercial or military applications.[2] Research into quantum mechanics by physicists in the 1920s laid the foundation for a microelectronics industry that did not begin to appear until the 1950s. Physicists first began to discuss nanotechnology in the late 1950s, but products did not begin to appear until the 1990s. Skeptics greeted DOD-funded research on lasers in the 1960s as "a solution in search of a problem," but twenty years later, it had revolutionized telecommunications and manufacturing.

The dilemma this interval creates is that the damage from a shortfall will not appear for some time. Further, once the damage is noted, there will be an interval between the new investment to repair damage and the renewed flow of benefits to society.

The U.S. finds itself in this situation today. There has been a shortfall in key areas for basic research for many years. The effect of a shortfall in basic research in the physical sciences is particularly dangerous for national security. Investments in basic research made two or three decades ago provide the technologies that are transforming the U.S. military and generate much of the growth in national economic productivity. Leadership in advanced technology is critical to expanding U.S. military capabilities and to maintaining an advantage over new kinds of threats and potential opponents.

Finding additional funds for basic research will be difficult. The President has identified his three budget priorities as winning the global war on terrorism, defending the American homeland, and moderating any increase in discretionary spending. The U.S. faces serious (if temporary) budget constraints. This is not the easiest year to consider an increase in Federal funding for basic research in the physical sciences.[3]

The three Presidential budget priorities identify the most immediate and most dangerous threats. They do not include America's long term strategic challenge. It is this long term strategic challenge created by global competition that puts U.S. security and the national

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[2] Joseph Schumpeter, an economist writing at the beginning of the 20th century, argued that innovation – the development of new products and new methods of production – was the source of economic growth.

[3] Congressional Budget Office, "An Analysis of the President's Budgetary Proposals for Fiscal Year 2006," March 2005

interest at risk. The United States must of course win the battles of today, but it can do so in a fashion that does not leave it vulnerable a few years hence. While U.S. funding for R&D is at a record high, we have been increasing emphasis on development while underinvesting the basic research critical for the new strategic environment and our future economic and national security.

Some of the consequences of this underinvestment are already apparent – a shortage of clearable U.S. citizen scientists qualified to work in Defense laboratories and the defense industry on sensitive national security projects. Other damage – a shortfall in the research that feeds the innovation pipeline - may not appear for another five to ten years. The U.S. still leads, but its lead shrinks every year.

The effect on security of underinvestment is acute and damaging in specific research areas. These include physics, mathematics, computer sciences, and engineering, research areas where the dangers of underinvestment are greatest. Research in these areas provides the basis for improved military performance. In relative terms, these areas have been the most seriously underfunded. Finally, advances in these research areas enable other areas of research – by providing better sensors and measuring tools or improved computing power.

In many areas, the U.S. scientific establishment is foremost in the world. America's 'soft infrastructure – laws, capital markets, culture – that turns research into innovation and innovation into economic and military strength give the U.S. a serious advantage over competitors. But there are disquieting trends. The U.S. leads, but its lead shrinks every year. This report will identify those trends, describe their implications for the long term national interest in a period of strategic competition, and discuss potential remedies.

Research and Security

> "Disruptive future challenges are those likely to emanate from competitors developing, possessing, and employing breakthrough technological capabilities."
>
> The National Military Strategy, May 2004

The U.S. and other nations realized in World War II that sustained scientific research provided military advantage. The United States created institutions and policies in the 1940s and 1950s to support scientific research. Continued support for these policies and institutions by Congress and Presidents explains much of America's success in the last sixty years.

Scientific research and innovation did not play a very large role in security or strength before the First World War. The resources devoted to science were miniscule. The opening battles of 1914, with their cavalry, massed infantry and horse-drawn artillery would have been familiar to Napoleon. By the end of the war, this had changed. As armies faced stalemate in the trenches, the conflict created a need for new technologies in communications, transportation and weaponry. This gave technology and innovation a central place in warfighting and in building national strength.

In the interwar period, government support for science was still limited. The Federal contribution to basic research in the 1930s averaged only a third of a percent of GDP. This changed with World War II. Science and technology became a force multiplier, and the U.S. developed institutions to link the scientific community to national security problems. The creation of the National Defense Research Committee (NDRC), established by leading scientists in 1940 under the auspices of the National Academy, to organize research for military purposes and to develop new technologies and operational strategies, institutionalized this linkage.[4]

The Manhattan project is the best-known example of the role of science in the Second World War, but decisive advances in anti-submarine warfare, encryption and computing, sensors, aircraft engines and rockets all drew heavily on the physics, chemistry, mathematics and engineering communities to produce military advantage. Victory against the U-boats in the Battle of the Atlantic came from science. Other examples include the proto-computer 'bombes' used to help break the enigma code, radar, jet engines, homing torpedoes and guided missiles. World War II's incorporation of science into military activity continues to define the relationship between national security and research.

The Cold War reinforced the importance of scientific strength. U.S. policy, beginning with Presidents Truman and Eisenhower, made federal support for a strong research community a vital part of national security strategy. The U.S. made the link between research and defense permanent in the 1940s and 1950s with the creation of a series of new agencies including the Office of Naval Research, the Atomic Energy Commission and the National Labs in 1946 and the National Science Foundation in 1950.

The U.S. further expanded the role of research in security in 1957, after the Soviet Union launched Sputnik, the first artificial satellite to orbit the earth. The launch shocked the U.S. and led to predictions that Soviet superiority in math and science education would give it global leadership within a decade. In response to Sputnik, the U.S. created the Defense Advanced Research Projects Agency (DARPA), whose mission was to ensure military superiority for the U.S. by fostering new technological innovations. Congress passed into law the National Defense Education Act (NDEA) to subsidize education in the sciences, mathematics and foreign languages. The Sputnik surprise showed America the dangers of resting too long on past successes.

More importantly, it became apparent that the U.S. would not be able to match the quantitative advantage of the Soviet bloc in tanks, aircraft, missiles and other weapons. The ability of the arsenal of democracy to out-manufacture the Axis powers had been one of the avenues to victory in World War II. The Cold War closed that avenue – America would not be able to outbuild its opponents. American strategists looked to gaining a qualitative advantage over opponents to provide for an effective defense. Qualitative

[4] The success of the NDRC led the U.S. to expand it in 1941 as a renamed and more powerful entity, the Office of Scientific Research and Development.

advantage came, in large part, from the technological superiority produced by consistent, long term Federal support for research.

A series of changes in warfare reinforces the importance of technological superiority. The first Persian Gulf War showed that a new kind of warfare had emerged. It depends on greater use of information collected by advanced sensors, including space-based sensors and better communication among commanders and combatants. The work of military theorist John Boyd, which emphasized making decisions faster than opponents, helped to shape the new approach.

The current emphasis is on military Transformation. Transformation seeks to change the U.S. military into a force defined by mobility and swiftness, one that is easier to deploy and sustain, and which relies on stealth, precision weaponry and information technologies for superiority over its opponents. In the future, combatants will be integrated with sensors, information systems, and weapons. Data will be networked, automatically processed and then rapidly diffused among combatants. The concept of information dominance is central to the new style of warfighting, but increasing information dominance will require improvements in a range of technologies and in the engineering skills required to integrate them.

The changes in warfare have placed an increasing emphasis on technological superiority. Defense transformation, the latest effort, depends on a set of technologies –information technology from software to robots; aerospace; advanced materials and stealth; and sensors. It needs advanced engineering skills for development and integration. Progress in military transformation will depend heavily on physics, chemistry, engineering and computer sciences to provide new forms of propulsion, advanced materials and communications. These are the research areas with the greatest military utility and, unfortunately, they are the areas that the U.S. has consistently underfunded for many years.

Heavy industries and mass production of platforms (tanks, ships, and aircraft) is no longer the foundation for security. Nations whose defense industries aim at mass production will find themselves building targets, not weapons. To ensure its future military strength, the primary requirement for the U.S. is to expand its ability to generate new knowledge and technologies and rapidly apply them to military and security problems.

Support for basic research is essential for a strong defense industrial base. Basic research expands the pool of knowledge upon which engineers and scientists can draw upon to find solutions to military problems. Investment in basic research supports the University research and engineering departments that produce both new technology and a technological workforce.[5] While the lag between basic research and the application of that research can be measured in years, this production of new knowledge is crucial to

[5] Approximately 40 percent of all academic engineering research is supported by the Department of Defense.

technological superiority.

This is particularly important given the range of potential new threats that the U.S. faces both abroad and at home. Much of the military technology that the U.S. depends upon was developed for a very different sort of opponent – a nation state with large conventional and strategic military forces. The new asymmetric threats are very different and require rapid advances in technology to develop effective defenses and to maintain the U.S. military advantage over opponents.

Most people are familiar with the story of the Internet as an example as to how investment in research provides dramatic benefits to society. DARPA funding that commenced in 1969 allowed a small group of researchers to lay the technological foundations for one of the longest periods of sustained growth in U.S. history. The problem with this story is that if we begin it in 1969, we are really starting in the middle. The success of the creators of the Internet rests on work in mathematics, engineering, physics and other sciences that date back to the 1940s.

The work that led to the internet is better seen as the development over a period of years of a critical mass of new knowledge from a range of disciplines that could be applied to solve problems in both economics and security. DOD investments in atomics clocks (the base technology for the global positioning systems and for mobile telephones) provide a similar story of basic research generating immense economic growth years after it was begun. Refreshing and expanding the pool of knowledge available to the U.S. is a critical national task that has now grown more important, in light of changes in the international environment.

Maintaining national security and economic strength will require advances in science. Key areas for future innovation include information technology, biotechnology, advanced materials, semiconductors, and energy alternatives. The key areas for military innovation include the development of new material and power sources, bioscience performance enhancers for soldiers, robotics, decision support software, sensors, and large-scale integration of new technologies into complex new systems.

Energy is an area that offers immense opportunity. The Iraq experience showed that the batteries to power the radios, computers, night vision goggles and other high-tech equipment have become an essential element of logistics. There are stories of a sharp spike in world demand for batteries as operations began in Iraq. Soldiers had to replace these batteries every few days. Obtaining thousands of different sizes of batteries and getting them to military units spread over hundreds of miles, in a situation where front lines were fluid at best and battles frequent and unpredictable, put a considerable strain on supply chains.

Military vehicles still depend on combustion of fossil fuels. We use the descendents of the early steam engines that burned coal or wood to produce power. This is a problem for the military and for the larger society. The military appetite for oil is immense and the problems of and costs involved in resupply can be staggering, especially when undertaking major military operations. Development of a source of motive power that did not depend on combustion of fossil fuel will offer tremendous benefits to society, one of which will be improved military performance.

These advances will not appear automatically. They require the support of a strong scientific base and a strong foundation of research in the physical sciences. This is the lesson the U.S. learned in the 1940s. But the U.S. advantage is shrinking as other nations' scientific and technological capabilities grow. A decline in Department of Defense support for basic research compounds the damage from the narrowing of the U.S. technological advantage due to increasing foreign capabilities. While the overall DOD research, development, test and evaluation (RDT&E) budget has grown dramatically, this has not been mirrored in basic research (known as the 6.1 account in DOD budgeting). A December 2004 assessment by the National Research Council found a ten percent decline since 1993 in purchasing power for DOD's basic research.[6]

Independent research and development (IR&D) investment by the defense industry has also shrunk. In the past, about three percent of DOD spending on procurement ultimately went to IR&D. However, the decline in procurement of new equipment has reduced the amount of funds for technological innovation for the military. In addition, support for basic research has shrunk as government and private defense R&D investments must go to pressing near-term priorities rather than to creating fundamentally new capabilities.

This changing environment in science and technology paints a discouraging picture. Innovation in areas critical to our national and homeland security are increasingly likely to occur outside the U.S. A nation that can lead in science and make the research breakthroughs that enable innovations in energy supply, motive power, sensors or weaponry, will gain an immediate advantage.[7] The collaborative and international nature of science reduces the risk of monopolization, but the possibility of rapid scientific advance in another nation at the same time the U.S. is slowing basic research creates a new and troubling are of asymmetric risk for the United States.

A New Strategic Environment (July 7, 2005)

> "They [China] are not asking for a military contest for power, but for an economic competition."
> Lee Kuan Yew, 2005

The last fifteen years has seen the emergence of a strategic environment very different from what many Americans expected at the end of the Cold War. This goes beyond the surprise of having to wage a global war on terrorism. Terrorism is the immediate threat, but the larger risk comes from growing strategic competition.

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[6] http://www.nap.edu/openbook/0309094437/html/19.html

[7] Joint Chiefs of Staff, National Military Strategy of the United States of America; A Strategy for Today, A Vision for Tomorrow," May 2004, www.oft.osd.mil/library/library_files/document_377_National%20Military%20Strategy%2013%20May%2004.pdf

This is a complex and competitive international environment. The United States has gone from leading an alliance of Western democracies in a global defense against a superpower foe to a world where alliances are less cohesive and threats are more diffuse. The immediate hazards lie with terrorism, weapons of mass destruction, and problematic non-state actors, but the long term strategic challenge lies with the emergence of powerful new states. This strategic competition is not a conventional security problem and it is not fully recognized by the policy process. The new competitors include nations, among them China, who see themselves now or in the future as challenging the U.S. for economic power, international influence and regional or global leadership. This is not a military struggle, although military strength is an aspect of the competition and, at least in China's case, military conflict cannot be ruled out.

Strategic competition does not rely on violence to determine who is ahead. Strategic competition is an indirect kind of national competition that occurs over the long term. From a macro perspective, however, this strategic competition holds a much greater potential to affect the U.S. national interest and security.

U.S. military predominance has changed the nature of competition. First, no potential competitor is rash enough to contemplate direct military action against the United States. The immediate result is that competitors look for asymmetric advantage – to compete with the U.S. military in areas where we are vulnerable or where our lead is not so pronounced. Terrorist attacks seek to exploit the vulnerabilities created by our open society. Nation-states look for advantage in information warfare, attacks on space assets, or in the use of unconventional weapons.

U.S. military predominance also shifts competition into the economic and commercial arena. Technological and scientific leadership gives the U.S. considerable influence in international affairs. Other nations are duplicating the U.S. investment in science and technology in order to compete by increasing their soft power.

The problem is made more complex because it is in our national interest to see these potential competitors grow economically. U.S. policies encourage some of the trends that create competitions – the opening of global markets for investment and trade, the open discussion of ideas and the free movement of workers and researchers. These policies provide immediate benefits to the U.S and offer the prospect of a more prosperous and stable world. The U.S. goal is not to prevent competitors from growing, but to ensure that America grows as fast as or faster than they do. The U.S. needs foreign policies that encourage others to grow, but it must match these with domestic policies that maintain U.S. leadership.

The long term result is that nations compete by seeking to surpass the U.S economically and technologically. The U.S. is the benchmark by which other nations define their growth and success. The flow of international politics, driven by displeasure, concern or envy for a perceived U.S. preponderance, creates nationalistic motives that drive efforts at development. The dangers of terrorism and the short-term focus of politics and business make it easy to overlook this, but the real competition for the U.S. lies in this race for economic growth and technological leadership.

Who are our strategic competitors? A few other large nations are striving to match and ultimately exceed the United States in terms of economic strength and technological prowess. These nations have large populations, continental land masses and strong (or increasingly strong) science and technology capabilities. They include China and India, but also Europe and possibly Brazil and Russia. Their motives for competition are a combination of a desire for economic growth and a reactive response to assert their national interests in the face of U.S. leadership.

In some cases, such as with China or in Europe, there are explicitly stated goals to diminish U.S influence in global affairs. Many Europeans hope to see the EU emerge as an economic superpower that will counterbalance the U.S. military 'hyperpower.' While aspects of the transatlantic relationship remain strong, Europe can often only define itself through contrast and competition with the United States. Chinese leaders make no secret of their desire to displace the U.S. in Asia. China is the emerging power of greatest concern, because its rapid economic growth is combined with an opaque and undemocratic system of government, its perceived ambitions, and because of the potential for conflict over Taiwan. The hopes that a wealthier, market-oriented China will become a stable democracy have not yet been fulfilled. China's military modernization undercuts its assurances that its intentions are peaceful. Economic interdependence between the U.S. and China continues to grow, but it is not yet matched by an increase in trust.

Each potential competitor has its strengths and weaknesses and in relative terms, the U.S. remains stronger. But, these terms are shifting in ways that could prove unfavorable to the long term interests of the United States. Four interconnected trends explain this shift. They are: the rise of Asia; the transition to an information economy; the advance of commercial technology; and the technological diffusion produced by the growing international economic integration.

The Rise of Asia

> "In the same way that commentators refer to the 1900s as the 'American Century,' the 21st century may be seen as the time when Asia, led by China and India, comes into its own."
>
> National Intelligence Council, "Mapping the Global Future, 2005"

The global economy is now centered on the Pacific Rim, which produces 60 percent of the world's GDP. This shift from Europe to Asia is the result of rapid industrialization and economic growth, beginning in Japan and moving in sequence to Taiwan, Korea, the ASEAN Tigers, China, and now Vietnam. Rapid industrialization in Asia was the result of heavy, government directed investment in manufacturing capacity. Asian nations now plan to duplicate their success in manufacturing by following a similar pattern of investment in knowledge creation and innovation.

They are making these investments in knowledge creation and innovation because, as their economies mature, they face the same economic pressures found in the U.S. and Europe. Until now, much of Asia's economic growth resulted from capital accumulation from high domestic savings rates and large inflows of foreign investment. However, there is a limit to growth solely from increasing the factors of production. When this limit is reached, continued growth requires improvements in technology and productivity. Japan, Korea and perhaps Taiwan are already at this plateau. China is approaching it. Asian economies must either promote knowledge creation or face economic stagnation.

The leading Asian economies have recognized this challenge. Asia is beginning to play a critical role in research and innovation. This is not an accident. Many Asian countries have studied how the United States has succeeded and concluded that support for scientific research and the development of strong universities are key ingredients for success. At the same time, the most advanced Asian economies – Japan, Korea, Taiwan – worry that manufacturing will flow from their countries to lower-cost nations in Asia, particularly China, and see innovation and knowledge creation as a way to respond to this flow. In turn, China looks to knowledge creation to improve its security, allow continued economic growth, and reduce or end its reliance on foreign technology.

The growth in manufacturing in Asia is mirrored by growing R&D capabilities. From 1995 through 2001, gross R&D spending in China, Korea and Taiwan increased by about 140%, while in the US it increased by 34%. Figures from the World Intellectual Property Organization show that in 2003 patent applications from Japan increased by 15% (to 19,982), by 19% (to 3521) for South Korea, and from China by 38% (to 1782) . Chinese R&D expenditures ($60 billion) rank third in the world behind the U.S. and Japan. India is now in the top ten countries for R&D spending. India and China have each seen more than one hundred Fortune 500 companies open research centers in their countries to take advantage of the skilled labor force.

Accumulation of human capital[8] is another attribute of Asia's rise. The National Science Foundation reports that Asian universities accounted for almost 1.2 million of the world's science and engineering graduates. European universities accounted for 850,000. North American universities accounted for only about 500,000. Students from China, Taiwan, India, and South Korea earned more than half of the 148,000 U.S. science and engineering doctoral degrees awarded between 1985 and 2001 to foreign students. There is anecdotal evidence that suggests an outflow of Indian, Taiwanese and Chinese researchers educated in North America, who are now returning to Asia as living conditions and economic opportunities there become more attractive.

Japan and Korea are also accelerating their efforts at knowledge creation. From 1995 to 2002, Japanese businesses increased their R&D spending from 2.12 percent to 2.32 percent of GDP. Japan has always invested heavily in R&D. Now there are indications that it is increasing investment in basic research. For example, it is the practice of the Japanese government to match or exceed the annual U.S. federal investment in nanotechnology. Korea has committed to a policy of doubling its R&D expenditures.

[8] Human capital is the stock of knowledge and skill embodied in a population.

Whether these countries actually carry out these ambitious plans or not, we are already seeing signs of R&D acceleration.

Taiwan has begun an effort to move from manufacturing to “knowledge-based” services as the way to guarantee continued growth. Taiwan has unveiled a number of “flagship plans” that include expanding broadband internet services, improving education, and expanding Taiwanese design and information services (particularly for information technology) where the market is currently led by U.S. firms.

China is, of course, the focus of attention. Between 1995 and 2002, China doubled the percentage of its GDP invested in R&D, from 0.6 to 1.2 percent. This is still small, but China says that it intends to double the proportion of its science spending devoted to basic research to about 20 percent of its science budget, in the next 10 years.

China is becoming a leading center for research and development. It is recognized as home to a skilled technology workforce. Many companies are attracted to invest in China to gain access to this workforce. Most new R&D facilities are still concentrated in the telecom and software sectors and focus on developing new products for the Chinese market, but some companies (such as Microsoft and Intel) are now investing in China’s research capabilities in order to service the larger Asian or global markets. China is now second only to the U.S. in the number of researchers in its workforce.[9]

China’s case is instructive as it is a deliberate effort to catch up to and overtake western nations. In the mid-1980s, in reaction to new R&D programs in the U.S., Japan and Europe, prominent Chinese scientists wrote to Deng Xiaoping, saying that China was falling behind industrialized countries in developing the advanced technologies that would be the key to national power in the future. Deng responded quickly, and China created the High Tech Research and Development (863) Program, which invests in high tech R&D projects to improve Chinese security and international competitiveness. China had three motives in creating and continuing the 863 Program. They are a desire for national prestige, a desire for commercial competitiveness and a desire to improve national security, by building a strong economy, developing the means to build high tech weapons and by reducing reliance on suspect foreign products.

The 863 Program and subsequent efforts fund R&D at Chinese research institutions and universities (and now companies) in nineteen technology areas, including information technology. Its general principle for selecting projects is to “combine military and civil use, with emphasis on the latter.” At first, the R&D funded by the 863 Program produced technologies that were neither advanced nor commercially competitive. This is no longer the case. The reasons for this are not only a maturing of Chinese R&D, but more importantly, a shift in how R&D is funded and managed. This change reflects larger trends in China’s economic policy to privatize, allow expanded foreign participation and to introduce market disciplines. This blend of government support and private sector activity is one key to explaining China’s emergence into the global market.

[9] http://www1.oecd.org/publications/e-book/92-2003-04-1-7294/A.12.3.htm

Most research institutions were affiliated with the Chinese Academy of Sciences (CAS) or with the Peoples Liberation Army (PLA). CAS alone has roughly 100 affiliated research institutions throughout China. Since the 1990s, both CAS and the PLA have pushed to privatize and commercialize their research. The large investment in research and education means that China has an advantage over many of its potential competitors in the developing world as a result (despite the disruption caused by the 1970s Cultural Revolution, which sent physicists and engineers to harvest rice).[10]

Government spending on education and R&D through programs like 863 or the Ministry of Science and Technology's Torch Program provides an indirect incentive for foreign firms to locate in China. Government investments in education and training (i.e. human capital) were an indirect subsidy that made China an attractive destination. China has created a relatively large pool of engineers and programmers available at low cost. OECD figures show that China has 743,000 researchers, compared to 1.3 million in the U.S. and 648,000 in Japan, but the U.S. lead is shrinking as more Chinese pursue scientific careers and an increasing number of Chinese citizens are receiving a higher education.

Indian leaders have also set the goal of increasing India's presence in science and technology. However, outside of a few strategic areas such as space and missiles, India's national plans for doing this are less developed and not as well supported as are those of other Asian countries. India's real strength currently lies in human capital. India produces 12% of the total global supply of university graduates, and this percentage will increase as more Indians gain access to higher education. Many of these graduates go on to higher training and employment in the U.S., but while those immigrants once used to stay, many now return for the opportunities that can be found in India.[11]

China and other Asian nations all have ambitious plans. We should not assume that they will succeed in achieving all of their goals. However, even partial success is shifting the landscape of technological innovation. On the commercial side, U.S. companies can and have taken advantage of growing Asian capabilities by recruiting skilled employees and, increasingly, by placing R&D centers in Asian countries. This allows them to benefit from increasing capabilities and maintain competitiveness. The same solution is not as available for security-related research and much of the U.S. defense industry. The nature of U.S. political relations with Asia complicates the issue. In Europe, where most nations are U.S. security partners, foreign technological advances could reinforce U.S. security. In Asia, where many nations are not security partners, we cannot assume that the same benefits will accrue automatically.

The Atlantic was the economic center of the last century. In this century, the world's economic center will be the Pacific. The U.S. is fortunate in this sense as it is a Pacific nation. The rise of Asia will, in the right circumstances, be beneficial for the U.S. by

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[10] Chinese Academy of Sciences, http://english.cas.ac.cn/eng2003/news/detailnewsb.asp?InfoNo=20964

[11] http://www1.oecd.org/publications/e-book/92-2003-04-1-7294/A.12.3.htm; "India's Brain Drain Eases Off," Washington Post, 2000, http://www.indianembassy.org/US_Media/2000/pm_us/India's%20Brain%20Drain%20Eases%20Off.htm

providing new opportunities for investment, by creating lower cost supply chains and by increasing demand for U.S. goods and services. The U.S. has been closely involved in Asian economic and security issues for more than century, and has played a central role in the region since the Second World War. But the economies of Asia bring a new level of competition; they are not the moribund Soviets or slow moving central planners. This race will be harder than those the U.S. has faced in the past.

Theses changes are neither unexpected nor injurious. A wealthy Asia is preferable to an impoverished one, and the U.S. and other nations have worked for decades to help Asian countries develop and modernize their economies. But as Asian countries increase their stocks of human capital and expand their economies, the relative position of the U.S. will decline. This too, is not inherently injurious. The U.S. has seen a relative decline in its share of global output since the 1950s while at the same time its international position became stronger. The real issue is not the rise of Asia but how the U.S. responds to it.

Globalization and the Information Economy

> "Globalization's most significant manifestation is the irresistible leveling effect it is having on the international military-technological environment in which DOD must compete."
>
> Defense Science Board, 2000

The international economy is in the middle of a great transition. Two related trends shape this transition and emphasize the need for increased research. These are the increasing value of information and human capital, and the growing international economic integration known as globalization. Together, they are producing an integrated and interdependent economy where knowledge creation will be the most valuable activity. These trends reframe the debate over what level of funding is adequate for basic research.

An information economy is one where the creation of new knowledge and services produces the most value for society. Investments in creating new knowledge or services will produce more income than investments in agriculture, mining or manufacturing. The transition to an information economy means that investing in scientific research will become more important in the future than it is now. Increasing the production of new ideas is the key to success in an information economy. In relative terms, the U.S. will do better if it shifts more resources to knowledge creation.

The transition to an information economy shapes international competition. Economic forces are moving many countries to increase knowledge production and strengthen their capabilities for research. Knowledge production will be the key to economic strength in the next century. Policies that focus on producing knowledge are more likely to generate growth and new technologies. In part, this is because some manufacturing activities are shifting to lower cost producers, but it is also the natural outcome of two centuries of industrialization. Every year, fewer factories make can more goods. This frees up resources, which, if they can be put to productive use, can find new ways to generate wealth and growth.

This is a difficult transition in part because it involves a shift away from manufacturing. The number of manufacturing jobs in the United States has declined since the 1970s, because of increased productivity in factories and because of increased trade and international competition. Agricultural employment is a historical analog to this transition. Farm ownership and agricultural jobs in the U.S. peaked in the 1870s and have declined ever since, but the end of the agricultural economy and a shift in labor and investment to higher value activities did not weaken the United States.

That less effort in manufacturing can make a country wealthier is counterintuitive and the transition is not without risk. Pittsburgh has torn down the mills along the Monongahela that made it the world's biggest steel town, but after some pain, it is richer than it was before. Pittsburgh was fortunate to have two leading universities and a strong service sector. Other cities have not done so well and mismanaging the transition from manufacturing can produce rust belts as well as new wealth.

The U.S. will need to compensate for any diminution of manufacturing by finding other ways to boost knowledge production. Innovation can come from 'breakthrough technologies,' but also from incremental improvements to existing products. Those who make a product are more likely to discover how to improve it. Greater dependence on a global supply chain means that the U.S. might lose the boost to innovation provided by manufacturing. The move to an information economy means that in certain fields – engineering, computer sciences, and chemistry in particular.

Globalization is the term used to describe the international integration of markets for manufacturing, investment and services. Globalization is not an accident. U.S. foreign and economic policies since the 1900s have promoted free trade, open markets, and the rule of law as the basis for a new and better international order. Technological change reinforces globalization. It provides unprecedented mobility for goods, people, and ideas and creates new networks for communications and commerce. International economic integration affects U.S. national interests and technological leadership by spreading expertise and manufacturing capabilities around the world, by impelling other countries to try to duplicate the U.S. success at innovation, and by reducing the advantage technology has given the U.S.

U.S. regulations inadvertently reinforce globalization's technological leveling. Homeland security initiatives have accelerated the loss of technological and economic leadership. In addressing legitimate security concerns, we have inadvertently made the U.S. a less attractive destination for investors, students, and researchers. U.S. export restrictions have also damaged University-based research and the international competitiveness of U.S. high tech firms. The result is the erosion of economic and technological advantage.

Globalization has changed the conduct of scientific research, making it more international and collaborative. Collaborative efforts involving teams of researchers from different nations are common. Private sector international research and development alliances have increased eight-fold since the 1980s. Companies have located plants or development centers in different countries or even different continents. They ship ideas for research and development quickly back and forth among these facilities to gain competitive advantage in a global market place.[12] Foreign companies spent roughly $20 billion dollars in the U.S. on research and development, and U.S. companies spent $14 billion on research and development in foreign countries. Of that, companies spent more than $1 billion in 'emerging' countries - India, China, Israel, and Taiwan. The overall effect is to increase the productivity of research worldwide, but at the same time diminish the U.S. scientific and technological advantage.

The increase in foreign direct investment (FDI) also speeds the diffusion of technology, by building new research and manufacturing facilities around the world and by transferring skills to employees. FDI holds tremendous benefits for the U.S. The U.S. is the largest recipient of FDI from other countries. U.S. investments overseas produce greater returns that strengthen the U.S. economy. At the same time, however, FDI is a significant contributor to technological diffusion. The former head of the World Trade Organization noted that foreign direct investment is "the most effective mechanism for the diffusion of productive know-how and capital around the world." [13]

Several different measures show the extent of this diffusion and the effect on the United States. These include the U.S. share of global R&D spending; the U.S. share of patents; and the U.S. share of scientific publications. In each of these categories, the U.S. share has declined. The number of science-and-engineering articles published by authors based in the United States remained flat throughout the 1990s, while authors in other nations significantly increased their output. Between 1981 and 2003, there was a 20-fold increase in publications by Chinese scientists in international scientific journals. China now accounts for over 5% of the world's scientific publications. Papers with authors affiliated to Chinese institutions now account for 10% of the literature in materials science, and for 8% of that in mathematics and physics.[14] Patent issuance shows a similar trend. Foreign companies received forty six percent of the patents issued by the U.S. in 1999.[15]

Foreign scientific and research establishments will grow in relation to the U.S., particularly in Asia. The implication for the United States is that it faces a relative decline. However, a relative decline, where the U.S. share of the total global effort diminishes, need not lead automatically to an absolute decline. The relative U.S. share of

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[12] "Globalizing Industrial Research and Development, Office of Technology Policy, U.S. Department of Commerce, September 1999

[13] Director General Renato Ruggiero**, "**Foreign direct investment seen as primary motor of globalization," February 13, 1996, http://www.wto.org/english/news_e/pres96_e/pr042_e.htm

[14] http://www.nature.com/news/2004/040906/pf/431116b_pf.html

[15] Task Force on the Future of American Innovation, "The Knowledge Economy: Is the United States Losing Its Competitive Edge?" February 16, 2005

the output of goods and ideas fell in the 1960s as Western European economies recovered form the war, and in the 1970s when Japan entered global markets, but that relative economic decline was accompanied by absolute economic growth for the U.S. This can occur again if the U.S. economy is able to restructure and reshape investment to fit the new environment.

The rise of Asia and global economic integration reinforces the transition to an information economy and increases the risks of that transition. As manufacturing shifts to Asia, research and innovation will follow (particularly if there is a strong scientific workforce to welcome it). Absent compensatory measures, the transition to an information economy and the flow of manufacturing to Asia will decrease U.S. technological strength. From a larger perspective, the increase in manufacturing in Asia is a positive if it signals that U.S. economic activity is moving to areas of higher return.

The transition to a knowledge economy requires a different set of skills from the U.S. workforce. The U.S workforce will need a higher level of basic education and an increased percentage of 'knowledge workers,' including a larger number of scientists and engineers. Funding for basic research will help determine how well this requirement is met, since basic research is one of the key ingredients for building an expanded base of knowledge workers.

Maintaining technological strength and competitiveness in this new environment requires a new focus for policy. This focus must encourage Americans to create new knowledge and use it faster and more efficiently than competitors. The U.S. has had a comparative advantage over other nations in generating new ideas, because of its culture and 'soft infrastructure' and because of the strength of its research establishment, but it is losing ground in its ability to create new knowledge from scientific research.

Advances in Commercial Technology

> "DOD faces clever, resourceful adversaries with access to militarily-relevant commercial technologies."
>
> Defense Science Board, 2001 Summer Study

Advanced technology is a key force multiplier. In the past, the U.S. military had access to technologies that were not available to civilians, but the gap between advanced military technology and commercially available technology is shrinking. This is another new risk to U.S. military superiority. This new risk grows out of the diffusion of scientific and technological capabilities. Commercially available technology can, in many areas, offer a potential opponent the opportunity to improve their military capabilities without requiring a strong defense industry or specially designed military products. A competitor with adequate resources could approximate (although not equal) U.S. military technology, by using commercially available technology from non-U.S. sources or by developing potentially formidable asymmetric attacks.

This is particularly true for many of the technologies that enable military transformation.

Computing power and communications technology in the commercial sector are equal to military technologies. Access to space services, such as satellite communications can rival what is available to the military and other space services, such as remote sensing and GPS can provide a degree of equivalence. Sensor capabilities continue to increase while prices continue to fall. A determined adversary with sufficient resources could use commercially available technology to mimic key U.S. capabilities in many areas.

Commercial technologies undergird the transformation of the American military. For a decade, the U.S. military has taken advantage of COTS – Commercial Off The Shelf – equipment to meet the requirements for developing a netcentric capability that improves combat effectives and is a central part of the larger transformational effort. In some cases, according to the Defense Science Board, commercial technology is more advanced than military technology. The networking, communications and processing capabilities required for netcentric warfare are based in large measure on commercial technology.

The U.S. has an advantage in these technology areas, but it is decreasing. The Annual Report of the Secretary of Defense to the President and Congress stated "technologies for sensors, information processing, communications, precision guidance, and many other areas are rapidly advancing and available to potential adversaries."[16] More importantly, foreign investment in basic research introduces a 'wild card' into the military technology equation. If fundamental advances in physics or other physical sciences increasingly occur outside the United States, the chances of a strategic competitor gaining military capabilities equal or superior to the U.S. increase. This is a new and unstoppable area of risk for U.S. security. The best way to mitigate it is to ensure that U.S. national investment in basic research in these areas expands at the same pace or faster than is the case for foreign competitors.

Other nations want to copy the U.S. military's high tech advantage. Improvements in commercial technology, particularly information technology, make it easier for them to do this. U.S. regulatory efforts aimed at denying access to advanced technology have in practice inadvertently contributed to the diffusion of technological capabilities and the creation of non-U.S. sources of advanced, militarily-useful technology. Space research is a prime example of this. By complicating the ability of U.S. research centers to acquire foreign students or collaborate with foreign partners, U.S. regulations have accelerated other nations' efforts to build their own research capabilities. Foreign governments and manufacturers have responded to regulations that make it difficult to obtain advanced U.S. components by investing in their own research and manufacturing capabilities for advanced technologies with defense applications. Efforts to restrict foreign access to technology have helped reinforce the new competitive challenge the U.S. faces today.

The difficulty of progress in some fundamental research areas compounds the problem. In several key areas of science such as propulsion and microelectronics, we may be reaching the limits of what can be done with today's understanding of physics. One result of the research investment emphasis on applied rather than fundamental research is

[16] Secretary of Defense, The Annual Report of the Secretary of Defense to the President and Congress, 2002," http://www.defenselink.mil/execsec/adr2002/index.htm

that we have accelerated our ability to use what we know today, while our creation of new knowledge has slowed. In effect, the leading edge of research had slowed down while the following edge of applied science and research is speeding up. A slowing pace in creating new knowledge narrows the gap between the most advanced technology and what is available in the commercial market.

In order to remain ahead of potential competitors, the US will need to remain ahead of commercially available technology. Given the dominance of commercial technology, a nation that has a strong research base will have an advantage, as this research base can better modify and improve commercial technology for military purposes.

As with the rise of Asia, globalization has benefited the United States. The U.S. has a competitive advantage in the global market, and the technologies and revenues produced for the U.S. by the global market have contributed directly to its military and economic strength. At the same time, the rapid advance of technology has also increased the challenge to American leadership. If the U.S. is to maintain superior military capabilities it will need to accelerate its own efforts to develop cutting edge technologies. Reinforcing and accelerating basic research in order to provide a continuous flow of technological innovation that is ahead of what is commercially available is the best means to achieve this.

Responding to the Challenge

> "Whether flatness is good for any particular country depends on how that country prepares itself for the rough and tumble of this flat world."
> Thomas Friedman, The World is Flat, 2004

These trends frame the situation for the United States over the next several decades. They point to long term shifts in international power from Europe to Asia, and to a new kind of economy. How the U.S. will fare in this continuum of change will depend in large measure on how well it manages the interrelated transitions these trends create. Great power status came easily to the United States a century ago as it mobilized its continental resources, but maintaining that status in the new century requires a different kind of effort.

Three technology areas –wireless technologies, aerospace, and semiconductors - demonstrate the challenge. These technologies play a crucial role in military transformation. Wireless technologies hold immense potential for both economic and military activities. Wireless research in the U.S. is declining while it is increasing overseas. Foreign competitors gain an advantage from funding provided by their governments for both short and long term research.[17] Over the long term, the result will be to shift innovation in wireless technologies outside the United States. This trend, if not reversed, will damage U.S. security.

The same pattern holds in aerospace. The President's Commission on the Future of the

[17] "Securing the Future: A Report of the National Research Council" May 2003

United States Aerospace Industry concluded that the U.S "has been living off the research investments made primarily for defense during the Cold War…"[18] Research and development for satellites and space has declined steadily over the last decade. As with wireless technology, leadership in innovation is beginning to shift from the U.S. to government-supported research overseas. Funding for NASA remains strong, but much of this funding has gone to support existing or proposed human space flight initiatives. Outside of these efforts, the U.S. is cutting most research programs, including those for aerospace research. An industry led study of the aerospace industry found that the decline in federal support for research directly affected the aerospace workforce, with a decline of "more than 750,000 scientific, technical, production, and administrative aerospace workers during the past 14 years."[19]

The U.S. semiconductor industry also faces challenges from well supported foreign research programs. As semiconductor manufacturing moves overseas, taking with it some of the boost to innovation provided by hands-on experience, the U.S. will need to compensate by increasing R&D efforts - leading edge research will migrate to production leaders absent some compensatory effort.[20] This is particularly worrisome because improvements in semiconductors have pushed the industry to the edge of our scientific knowledge. Future progress will depend heavily on advances in physics. As early as 1995, studies began to identify serious shortfalls in U.S. investment in the R&D needed to maintain leadership in semiconductors.[21] One analysis found that while the semiconductor industry has increased its R&D spending significantly, there is an R&D shortfall of $1 billion to $1.5 billion per year.[22]

In each of these key technology areas, the U.S. faces problems that will not be solved by market forces. This is contrary to the U.S. experience in many other areas, where private initiative is best at supplying impetus and direction for growth.[23] The problem, particularly for basic research, is that while the return on R&D investment can be substantial, this return will not accrue just to the investor and will not arrive in a fashion that is timely enough for markets. Self-funded basic research is a risky proposition for the private sector and therefore not viewed as a wise investment.

Any U.S. response to the challenges created by globalization and economic transition must be multifaceted. Increased funding for basic research will be only one part of an effective response. Improvements in tax policy, health care, education and telecommunication

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[18] Final Report of the Commission on the Future of the United States Aerospace Industry, p.9-2
[19] Aerospace Industry Associating, "Aerospace Research and Development, http://www.aia-aerospace.org/issues/subject/rd_brochure.pdf
[20] Defense Science Board, Task force on High Performance Microchip Supply, February, 2005, Page 25
[21] Howell, Thomas, "Competing Programs: Government Support for Microelectronics," pp 189-254 in National Research Council, Securing the Future: Regional and National Programs to Support the Semiconductor Industry, 2003
[22] John Schmitz, "R&D in the Microelectronics Industry--A Cautionary Assessment," June 21, 2004, Future Fab International, http://www.future-fab.com/documents.asp?grID=208&d_ID=2594
[23] "EU Versus US," TIMBRO, June 2004, National Academy of Sciences, Measuring the Science and Engineering Enterprise: Priorities for the Division of Science Resources Studies, 2000, Page 82 Office of Scientific and Engineering Personnel

regulations would all help the U.S. economy in a new era of competition. Reenergizing and strengthening the nexus between scientific research and security is critical, however, for defense and homeland security. This strengthening must in large measure be a Federal function. Absent increased Federal support, adequate investment in the right kinds of basic research will not occur, putting U.S. security at risk.

The broad issue is to determine where and what kind of government intervention can maintain technological leadership. The most important requirement for technological leadership is the ability to innovate – to create new ideas, goods, and services. Policies that reinforce innovation are the best safeguard for U.S. security. Technological innovation has many sources, but one source is worth additional attention because it provides the U.S. with comparative advantage. This source is the combination of university research programs, entrepreneurs, and risk capital (from venture capital, corporations, or governments) that is exemplified in clusters around Silicon Valley, North Carolina's Research Triangle, or the Boston-Cambridge Route 128. This clustering of science and engineering expertise with entrepreneurial skills and risk capital is a leading source of innovation in the U.S. One tribute to the strength of this system is that other nations are trying to duplicate the successful mix of basic research and business skills found in these clusters.

The linchpin of the system is the graduate educations and strong university research departments. Graduate research programs provide a constant flow of new talent and ideas to local industry. Funding for basic research in the physical sciences and engineering is essential to keeping graduate research programs strong. U.S. graduate programs are world leaders. Not only have these programs helped to train talented U.S. students, but they have also attracted talented foreign students to come to the U.S. to study and conduct research here. Many of these individuals stay in the U.S. long after completing graduate studies and make a crucial contribution to the U.S. economy. Finding ways to keep U.S. graduate programs vibrant, and to ensure that both the people and ideas they generate continue to flow into economic activity is perhaps the best single best strategy for maintaining technological strength.

These graduate programs depend on federal research funding. Private sector initiatives will be insufficient to maintain, much less expand, basic research. Private initiative and markets are very effective at supplying goods and services in most situations, but in some instances, the private sector alone will not produce the best outcome. This can be because risks are high or because any return from an investment is distributed broadly, benefiting both those who paid and those who did not. Basic research involves both high risk and diffused returns, making it less desirable for private investment. The traditional response to these 'market failures' is for government to intervene and make the investments that will not otherwise occur.

The greatest return to new investment in research will come from areas we have underfunded in the past. Basic research in the physical sciences and engineering is the area for investments that will yield greater returns and comparative advantage, in part because of their importance to military technology and in part because they are very often the source of enabling technologies for all other kinds industries and other fields of research. The investment in basic research in the 1970s and 1980s provided the intellectual capital for the high-tech economic boom of the 1990s. This funding is not being renewed at the same level now, suggesting that the well of innovation may begin to run dry in the next decade.

Federal Investment in R&D

> "If this Congress does not substantially raise the research budget, we are unilaterally disarming from the standpoint of international competition.""
> Newt Gingrich, 2005

While the U.S. continues to lead in many research areas, its investments are not enough to sustain this lead over the next decade. The problem lies with the absolute levels of investment, the distribution of investment among research activities, and the rate of change relative to other nations. While the current Administration has been generous in it support of R&D and science, a careful examination of where major funding increases have been provided suggests that much of the focus, especially in defense has been on development as opposed to research. Funding for basic research within the Department of Defense has been stagnant in real terms and experienced significant declines in purchasing power if one uses DOD's own costs deflators.

In domestic discretionary accounts, a majority of the increase provided to basic research comes from significant growth in the budget for biomedical and health research resulting from the doubling of the NIH budget. Similar growth has not been seen in federal support for basic science in the physical science and engineering fields critical to our national and homeland defense. This declining U.S. support for these areas, crucial to security, comes at the same time other nations are accelerating their spending in these areas. This is not a long term strategy likely to produce continued success. Several indicators point to future problems:

> If current trends in R&D spending continue, the fastest growing economies (including China, Taiwan and South Korea) will overtake the U.S. in nine to ten years.
>
> Federal funding for basic research in engineering and physical sciences has experienced little or no growth in the last thirty years. As a percentage of GDP, funding for physical science research has been in a thirty year decline and has fallen by about half.[24]
>
> Total federal funding for R&D was essentially flat from 1988 to 2001. Spending on mathematics research was roughly $190 million in 1985 and $200 million in 2004; spending on physics was flat between 1985 and 2001 and there were only slight increases in funding for chemistry.

[24] Task Force on the Future of American Innovation, "The Knowledge Economy: is the United States Losing Its Competitive Edge," February 2005, p.10

> Funding for engineering research increased from approximately $6 billion to $9 billion between 1988 and 2001, but funding for key research areas, such as electrical engineering, were essentially flat. In addition, it is not clear whether the increase represents new resources or simply accounting changes (particularly at NASA), and funding for academic research in engineering was flat over this period.[25]

The conventional metrics for research, publications, patents, number of science and engineering students, all show a U.S. lead that is being steadily eroded. While the decline in the relative share of scientific papers published by U.S. authors is not in itself troubling, the absolute rate of increase is worrisome. The number of U.S. authored papers increasing by only 13% between 1988 and 2001 while the number of papers authored by Europeans increased by 60% (and Europe overtook the U.S.). The number of papers authored by Asians more than doubled, increasing by 120%. Even more worrisome is that half of the U.S. publications were in the life sciences, whereas researchers in other nations concentrated on the physical sciences.

The U.S. has a record budget deficit and will cut spending in 2006. Discretionary spending, the source of a significant amount of federal funding for basic research, will bear the burden of deficit reduction. Discretionary spending was flat in 2005 and will likely fall 1-2 percent in 2006. OMB estimates that discretionary funding will then stay at the same levels for the five years after 2006.

Changes in the nature of R&D funding in the U.S. compound the effects of budget constraints. Over the past 30 years, the bulk of the funding for research and development has shifted from government sources to the private sector. In 1970, private industry funded only one-third of all U.S. research and development. Today, it spends nearly $200 billion annually, some two-thirds of the national total. But private sector research focuses on near -term results. Almost three quarters of private sector R&D funding goes to development, not basic research.

Intense global economic competition means that U.S. private sector R&D must focus more on development of new products for the market rather than on research. Only a small number of private R&D centers in the U.S. still perform basic research.[26] This is a rational business decision – a company that spent its R&D dollars on basic research might not survive to enjoy the results. Moreover, in terms of national defense, the defense industry has never engaged in the conduct of basic research but has always relied heavily upon such research to be funded by the Department of Defense and carried out at universities and DOD laboratories.

Trends in scientific research also have important implications for U.S. funding levels.

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[25] http://www.aaas.org/spp/rd/actrnd04.pdf and http://www.aaas.org/spp/rd/unidis04tb.pdf.

[26] Rick Whiting and Aaron Ricadela, "Future Funding: With the economy in the dumps, vendors struggle to keep investing in R&D -- and the future," Information Week, October 28, 2002. Whiting and Ricaldela found only three U.S. company labs still focused on basis research.

First, the distinction between 'science' and 'engineering' is disappearing in many areas. Second, there is a growing convergence of biology, physical science and information technology. The most productive research seems to emphasize interdisciplinary themes. Because collaborative areas do not fall under the jurisdiction of any one agency, they often run an increased risk of losing necessary funding. This means that shortfalls in investment in key enabling research areas will ultimately affect all areas of research. While the challenge is clear, a recent National Academies Study notes, "no consensus exists on the appropriate mechanisms or levels of support for research."[27]

President Bush has put forward a six point plan for economic growth: making health care costs more affordable and predictable; reducing the lawsuit burden on the economy; ensuring an affordable, reliable energy supply; streamlining regulations and reporting requirements; opening new markets for American products; and enabling families and businesses to plan for the future with confidence by making the tax cuts permanent. It would be worthwhile to add a seventh point to the President's plan for economic growth. That point would be to accelerate and expand the basic research that powers innovation in the American economy.[28]

Effect on the Science Workforce

> The harsh fact is that the U.S. need for the highest quality human capital in science, mathematics and engineering is not being met.
>
> U.S. Commission on National Security in the 21st Century

Federal support for basic research provides another important benefit that is vital for national security. It subsidizes participation by U.S.-citizens in the science and technology workforce. Businesses can, with the appropriate protections for intellectual property, hire non-U.S. scientists and engineers. Universities, in response to the increasingly collaborative and international nature of science, must be able to mix U.S. and foreign researchers. But for national security purposes, the U.S. (like every other country) must draw upon its own nationals.

The effect of flat or falling investment in basic research is seen first in the U.S. science and engineering workforce. Underfunding basic research reduces the flow of resources to university graduate research programs that are the source of a trained scientific workforce. Underfunding makes science less attractive to U.S. students as they decide which fields will be worth entering as a career. Sending coloring books promoting science to grade schools does not compensate for underfunding graduate study. The result of the underfunding of the last decade is already apparent, as sensitive national security positions that require U.S. citizenship are increasingly difficult to fill both in DOD laboratories and in defense industries.

Graduate enrolment in science and engineering bottomed in 1998 at 404,000 and has since recovered to reach 455,000 in 2002, a six percent increase. However, enrolment in

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[27] Securing the Future, P.40

[28] http://www.whitehouse.gov/omb/budget/fy2005/overview.html

some key areas (physics, mathematics, aerospace engineering) has declined 10% to 20% in the last decade.[29] Scientists and engineers leave underfunded fields for better funded research areas. Students in these fields watch their faculty advisors and peers struggle to receive funding and decide to choose other careers.

The number of undergraduates getting degrees in computer sciences is falling. 20,000 bachelors degrees in computer sciences were awarded in the 2003-2004 academic year, but new enrollment in computer science programs has fallen for a fourth year in a row, down 10% in 2003, with a cumulative decline of almost 40% since 2000. While the computer workforce is still recovering from the dot.com collapse, the demand for high level skills continues to grow.[30]

Aerospace science and engineering is another example. The aerospace industry employed twenty percent of American scientists and engineers in 1979, but by 2003, this has fallen to just three percent. In 1986, the aerospace industry had almost 145,800 engineers and scientists engaged in research, but shrank to almost 33,000 in 2003.[31]

Undergraduate and graduate degree programs have declining enrollment for aerospace science and engineering. Students are unwilling to enter an industry that is contracting and where interesting research projects are scarce. In addition, more than a third of the new aerospace graduates are not U.S. citizens and not able to obtain the necessary security clearances to work in defense-related programs. As the current workforce retires, and as the supply of replacements shrink, both government and industry find it difficult to attract the skilled personnel needed for aerospace programs.

The problem of a shrinking workforce is found across the defence sector. The National Defense Industry Association conducted a survey in November that shows that nine percent of all funded science and engineering positions in the aerospace and defense workforce are unfilled due to a lack of qualified candidates. DOD's Directorate of Research and Engineering warns that external forces are "inexorably eroding domestic U.S. S&E core competence to the point where the U.S. may no longer be the primary innovator in several areas crucial to future military technological supremacy unless the federal government takes significant actions to respond to those trends."[32]

Foreign participation has increased significantly to meet the demand that domestic sources cannot fill. The United States now ranks 17th among nations surveyed in the proportion of its 18-24- year-olds earning natural science and engineering degrees. In

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[29] Lori Thurgood, "Graduate Enrollment in Science and Engineering Fields Reaches New Peak; First-Time Enrollment of Foreign Students Declines," National Science Foundation, June 2004, http://www.nsf.gov/sbe/srs/infbrief/nsf04326/start.htm; Ed Frauenheim, "Students in the US saying no to computer science," CNET News, 12 August 2004, http://www.builderau.com.au/program/work/0,39024650,39130441,00.htm

[30] Michelle Kessler, "Fewer students major in computer," USA TODAY, May 23, 2005, CIO Today, "IT Staff shortage Looming," August 15, 2005

[31] http://www.aia-aerospace.org/issues/subject/employment_facts.cfm

[32] http://www.aia-aerospace.org/aianews/press/2004/rel_12_22_04.cfm; http://www.dod.mil/ddre/ndea_bkgnd.htm

1975, the United States ranked third.[33] This is the result of reasonable calculations by American students. Science careers are poorly paid in comparison with other opportunities (particularly in the first decade of work), and the training period is very long. In some fields, the average age for a scientist to become the principle investigator (i.e. gain independence in their research) is 41. A decreasing number of American students are willing to pay for a long and arduous course of study that promises an uncertain career path and salary.

As a result, the number of U.S. students pursuing science and engineering degrees applicable to defense and homeland security is falling. This comes at a time when there is an increasing emphasis on employing only U.S. citizens for work related to national security. DOD labs are facing attrition as scientists reach retirement age - one estimate puts the number of departures at approximately 13,000 in the next ten years. The departures come at the same time that overall demand for these skills will increase, with the result that DoD will face tough competition from the private sector for these scientists and engineers.[34]

The workforce shortfall reflects more than a decade of decline for basic research. Growth for the U.S.R&D budget was flat from 1986 to 2001 (fluctuating between $75 and $80 billion). Given the training time required for new entrants, we can expect a lag of several years between the increased that began in 2001 and an expansion of the science and engineering workforce. In addition, given the relative underfunding of the physical sciences and engineering, we can expect a continued shortfall in this part of the science workforce which is of greatest interest to DOD.

One international change makes the workforce issue even more critical. An influx of foreign scientists fleeing unstable conditions in Europe in the 1930s strengthened U.S. national security in the 20th century. The universities and institutions that received these scientists became global leaders in research, a role which they continue to play to this day. This benefited the U.S., as leading students from other nations came to these U.S. institutions to study and contribute to research.

However, several factors have made the U.S. a less attractive destination for scientific talent than it once was. Measures imposed since the attacks of September 11 have the unintended consequence of deterring some researchers from coming to the U.S. At the same time, other nations have recognized the economic and military advantages provided by scientific leadership and have attempted, with some success, to capture a greater share

[33] National Science Board, Science and Engineering Indicators 2004, National Science Foundation, 2004, http://www.bls.gov/cps/cpsaat9.pdf"
|http://www.bls.gov/cps/cpsaat9.pdf};http://www.bls.gov/cps/cpsaat10.pdf, National Science Board Companion Paper to "National Science and Engineering Indicators 2004", National Science Foundation, April 2004

of scientific talent and to duplicate the success of research centers found in the U.S. This means that the U.S. needs to compensate as foreign supplies of scientists and engineers shrink in the face of increased demand from other countries.

Research funding affects the decisions of individual companies as to which countries they will locate and which nations will lead in innovation for specific technologies. The U.S. decision to emphasis research investments in the life sciences is one of the factors that explain why some essential industries, like the semiconductor industry, are growing rapidly outside of the United States.[35] A decision to continue to underfund physical science and engineering will have long-term consequences for U.S. competitiveness and will ultimately damage national security.

The U.S. needs to increase the number of graduate students in science and engineering if it is to keep pace with the growth of international capabilities. Students respond to near term incentives (scholarships or other funding for their studies) and to their own long-term assessment as to which skills will provide a better career. The best way to increase the number of graduate students is to increase incentives. Providing direct financial incentives will encourage more undergraduates to enter science and engineering programs. An "enticement strategy," such as the proposed legislation for a new National Defense Education Act would increase the number of students in science and engineering. Expanding research funding for the physical sciences and engineering is an equally important incentive – better funded programs will attract more students and provide younger scientist with new and interesting work opportunities that currently do not exist.

Alternatives for R&D Investment (July 19, 2005)

> "The United States is in a long-distance race to retain its essential global advantage in S&E human resources and sustain our world leadership in science and technology."
>
> National Science Board, 2004

Congress has been generous with research funding and is well aware of the benefits research can bring to the United States. The issue now is how to increase this funding in a period of budgetary constraint, and make this increase a permanent part of U.S. national security and economic policies.

Appropriations from the discretionary elements of the Federal budget remain the best vehicle for funding basic research. This approach ensures adequate oversight by the responsible congressional committees, which is valuable for assuring that funding goes towards national goals. The appropriations process provides a number of benefits, but it also adds a degree of uncertainty to research funding. The funding process is competitive and research funding is one of many priorities that the Congress must consider.

Over the long term, increasing the actual appropriation for research remains the preferred

[35] Charles W. Wessner, editor. Securing the Future: Regional and National Programs to Support the Semiconductor Industry. (Washington, D.C.: National Academies Press), 2003.

avenue for increase, but Congress and the President may want to consider additional funding mechanisms to supplement appropriations. Discretionary funding provided by Congress can be buttressed by new measures that leverage existing allocations to maximize benefits.

The U.S. needs to develop a range of funding mechanisms for basic research in the physical sciences. A brief sketch of such mechanisms would include expanding the options for public-private partnerships, adopting nondiscretionary funding mechanisms, creating new incentives for private subsidies to basic research, and identifying new funding vehicles, such as endowments.

One solution would be to redirect existing funds already begin devoted to development and testing of defense technologies. Since FY 2001, there has been a significant increase for DOD funding going to the Development, Testing and Evaluation of major weapons systems (the DT&E of Defense RDT&E). Total funding for Defense RDT&E has grown from $40 billion in FY 2001 to $70 billion in FY 2005. But the research portion of RDT&E has not grown. A reallocation of just a few billion dollars within current RDT&E funds to basic research, as the development, testing and evaluation of current weapons systems is completed, could have a dramatic effect. Such a reallocation could at least help to ensure that we have the qualified U.S.-citizen science and engineering talent we need to meet our defense and homeland security needs.

The most common form of non-discretionary funding is an entitlement. An entitlement is a federal commitment to fully fund a program – health care and social security are the best known examples. Entitlements have been the fasting growing category of federal outlays since the 1950s, and gaining control of entitlements (rather than creating new ones) is the focus of long term budgetary reform. Many in the scientific community would welcome making funding for basic research an entitlement, but this idea is very unlikely to win Congressional support.

Non-discretionary funding could also involve Congress dedicating some percentage of the total R&D funding for basic research in the physical sciences– a commitment to automaticity in budgeting. This could be a useful counter to the drift towards more and more applied research or developmental work. A bolder step would be to earmark a percentage of Federal revenues for basic research (a kind of enforced national savings plan). This would essentially make funding for basic research non-discretionary. While Congress and the executive branch have been willing to set goals for basic research funding, they have been unwilling to surrender the flexibility that would be lost by translating these goals into mandates.

An expansion of existing corporate tax credits for company-based research is unlikely to benefit basic research, because additional tax credits or other incentives for corporate R&D would most likely be spent on development or applied research. Some business leaders state that business cannot assume the risks of long-term research, and corporate

R&D is focused on the next iteration of products or services.[36]

A more effective approach might be to provide tax credits for increased business contributions to university programs engaged in basic research. Modifying the existing tax credit for research would result in greater funding for basic research if corporations could receive tax credits for funds donated to an entity that supported basic research. Currently, companies do not receive full tax credit for research they support when it is conducted by an outside entity, such as a university.

Existing partnerships include the National Science Foundation's Engineering Research Centers (ERCs), government-industry-university partnerships where 80% of the funding comes from NSF and 20 percent from industry, states, and other sources. The Department of Defense has or had partnership programs, including the "Dual Use Science and Technology Program" where private sector participants bear at least 50 percent of the cost, and the Government/Industry Co-sponsorship of University Research (GICUR) program, which fostered long-term basic research at universities by pooling industry and government funds. Another Defense program, Technology Investment Agreements (TIA), requires private-sector partners to provide at least half of the funding, but in exchange, TIA programs are not subject to many of the regulatory requirements that apply to Federal grants. This sort of trade – basic research funding for a reduced regulatory burden (in anti-trust or in procurement regulations) would be an attractive incentive. The goal would be to create mechanisms for cost sharing, where the Federal government does not bear the total cost of the research project.

Another alternative for partnership is to establish independent consortia for basic research supported by both government and private resources. SEMATECH (SEmiconductor MAnufacturing TECHnology) was created in 1987 by fourteen U.S.-based semiconductor manufacturers and the U.S. government to strengthen the U.S. semiconductor industry. SEMATECH, while not primarily focused on basic research, allowed companies to leverage resources and share risks in pre-competitive research. SEMATECH initially depended on government funding, but now private firms provide an equal share of the budget . Semiconductors are one of the best examples of how government-supported research can remedy international challenges and generate long term benefits for national strength.

A new basic research consortium could be independent, or it could be placed under the auspices of an existing organization like the National Science Foundation.[37] New research consortia offer a cooperative approach to increasing the total national funding for basic research. While implementing this recommendation would require a commitment of funds and the development of an organization, tasks that will take both time and resources to achieve, the alternative may be to watch a continued decline in research funding.

[36] American Physical Society, Former Science Advisors Call on President to Shore Up Physical Science and Engineering Funding, April 7, 2004, http://www.aps.org/public_affairs/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=51738

[37] SEMATECH, "History of the Consortium," http://www.sematech.org/public/corporate/history/history.htm

NASA's Space Partnership Development (SPD) and Research Partnership Centers offer a similar example. NASA's 'Partnership Development Office' established consortia of academia, government, and industry focused on a specific field of research. NASA provided an annual base grant and the centers receive cash and in-kind contributions from industry, universities, research institutions, and other federal, state and local agencies. NIH also has successfully used a number of partnerships to pursue specific research programs.[38] An expanded approach similar to SEMATECH or SPD would require new legislative authority for different agencies to establish and fund partnerships, and possibly for companies to be shielded from anti-trust considerations.

New financial mechanisms could include creating a special class of Treasury bonds dedicated to basic research. The Federal government prefers general purpose bonds, but other levels of government routinely use special purpose bonds to fund specific projects (education, roads, etc). Budgetary legislation would require that the subsidy value of the bonds be scored against the federal budget, but the advantage of a bond issue for basic research is that it provides an immediate infusion of capital greater than the amount that could be provided by direct appropriations. New legislation would be needed to create this class of bonds. If that legislation provided the authority to 'roll over' the debt through the sale of new bonds as old bonds were retired, the actual cost to the government would remain low.

Alternatively, the Federal government could create a loan-guarantee program for third party bonds (issued by States, for example) to finance basic research. This guarantee program would most likely appeal to public entities. It would work like Export Import (ExIm) Bank or OPIC guarantees, where the U.S. guarantees repayment of a loan if the insured party is unable to meet its obligations. New legislative authority would be needed to create this class of guarantees. The subsidy value of the guarantee would have to be scored against the budget, so the guarantee is not without cost, but it provides a means to leverage Federal funding for basic research.

These are suggestions for approaches that could increase the flow of funds that would be available for basic research. It would also be useful to consider new approaches that would streamline the application process for some kinds of basic research projects or that would work to ensure a more balanced portfolio for research investments by the U.S. (no reasonable investor would put two thirds of their capital into biotech and space funds). The best single step might be to create a process that was responsible for identifying innovative approaches to research funding, drawing on members of the financial and scientific communities. An existing body, such as the President's Council of Advisors on Science and Technology could undertake the task or a new entity could be established. New policies and programs that leverage existing federal commitments and expand incentives for private investment increase the likelihood that the U.S. can repair the damage created by the current shortfall in basic research.

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[38] National Academies of Science, "Strategies to Leverage Research Funding: Guiding DOD's Peer Reviewed Medical Research Programs", 2004

Conclusion

> "It will be interesting to see how the race for scientific excellence unfolds in the new millennium."
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> Robert Fogel (Nobel Laureate in Economics), 2004

When the National Intelligence Council wrote "The rise of China and India as global players is heralding an Asian Century in place of a receding American Century," they were making a prediction that need not come to pass. There is nothing inevitable about a receding America, but America is facing a new kind of strategic competition and it will need to change if it wants to maintain its position.

What the U.S. faces is not 'imperial overstretch,' but a fluid new international economy where it must work harder and invest wisely to retain technological and economic superiority. Globalization, technological diffusion and the changing nature of scientific research all mean that we can no longer assume that leadership in technological innovation will fall automatically to the U.S. or that the bulk of innovation will occur here. Globalization has eroded the national character of science, but it has not changed the need for nations to draw upon science for their security.

Relative decline for the U.S. is unavoidable, but this need not translate into a loss of leadership. If the U.S takes advantage of and reinforces a combination factors, it can maintain its global position. Approaching this as a traditional 'S&T' issue will be counterproductive. The problem must be elevated and addressed as an issue of national security and economic performance. The key is to make maintaining technological leadership a central policy objective for the United States. An initial set of general recommendations would include:

1. **Restore funding** for basic research in the physical sciences and engineering across all domestic non-defense research agencies to the levels needed to meet long-term economic and U.S. national security requirements.

2. **Commit a larger proportion of Defense spending** within current Research, Development, Testing and Evaluation (RDT&E) funding levels to basic research and S&T workforce development.

3. Establish **new mechanisms for partnerships** with the private sector, other agencies and other governments (including both the state governments within the U.S. and allied governments outside) to support basic research.

4. **Create new governmental funding vehicles** (such as new incentives, special purpose bonds or endowments) to leverage current federal allocations.

The argument for increasing the investment is straightforward. American economic and military strength rests in good measure on its technological strength. That technological strength is the outgrowth of a dynamic process of innovation that connects the discovery of new scientific knowledge to economic and military activities. America's success in creating this dynamic, market driven process is envied by other nations and they are endeavoring to copy it. Basic research is the source of the knowledge that powers innovation and technological leadership. Basic research depends on federal funding. This funding affects not only the amount of research, but its nature and the number of people who will be available for national security-related employment. Decisions made today on the level and distribution of the Federal investment in basic research will affect America's influence and strength power for the next several decades.

Given the lag between R&D investment, particularly for basic research, and the return to the economy, there is a temptation in times of budgetary constraints to 'temporarily' defer funding. However, the U.S. has already deferred investment in the physical sciences for more than a decade. The reasons for this deferral involve a complex mix of factors– including the end of the cold-war rationale for R&D and changes in the U.S. education system. The conclusion of this report, however, is that the United States has inadvertently underestimated the costs of deferral and that the investment/return rationale for R&D must now be put in the context of a more focused and immediate national security need.

America may be at a disadvantage in this contest. In the strategic competition of the Cold War, an opponent with overtly military goals and a profoundly different political and economic system challenged the United States. The twin shocks of the 1950s – first the explosion of atomic and hydrogen bombs and then the launch of Sputnik - provided a sense of urgency that led America's political leaders to make the investments needed to pull ahead. The United States still benefits from those investments. Today, the challenge is more subtle. Instead of a single opponent, we face many competitors. There have been no technological shocks like Sputnik. The U.S. is not yet in a crisis, but it would be better if we did not have to wait for a crisis before deciding we should act.

About the Author

James A. Lewis is a senior fellow and director of the CSIS Technology and Public Policy program. Lewis, a former member of the U.S. Foreign Service and the Senior Executive Service, worked on foreign policy, national security, and technology-related issues at the Departments of State and Commerce. Since coming to CSIS, he has authored numerous publications, including *Globalization and National Security* (2004), *Spectrum Management for the 21st Century* (2003), *Perils and Prospects for Internet Self-Regulation* (2002), *Assessing the Risk of Cyber Terrorism, Cyber War, and Other Cyber Threats* (2002), *Strengthening Law Enforcement Capabilities for Counterterrorism* (2001), *Preserving America's Strength in Satellite Technology* (2001), and *China as a Military Space Competitor* (forthcoming). His current research involves innovation, military space, and the global information technology industry. He received his Ph.D. from the University of Chicago in 1984.

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