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ISB
Intelligence Science Board

Intelligence Science Board Task Force Report

on

The Intelligence Community and Science and Technology:

The Challenge of the New S&T Landscape

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Office of the Director of National Intelligence
Washington, D.C. 20511

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TASKING

June 9, 2006

MEMORANDUM TO: Dr. Anthony Oettinger, Chairman, Intelligence Science Board (ISB)

FROM: Dr. Eric Haseltine, Associate Director of National Intelligence for Science and Technology

I request the ISB undertake an analysis of trends in science and technology diffusion that threaten US superiority in S&T areas critical to the IC. As globalization spurs competition from foreign countries and erodes US predominance, it offers opportunities for new collection paradigms and places new requirements on US technology investment strategies. The IC's response to this growing challenge must be designed to match the pace of this growing global threat.

Particular attention should be paid to the pace of foreign efforts to compete across a broad spectrum of critical science and technology areas. The ISB should recommend actions to be taken by the DNI that ensure the IC moves efficiently and rapidly to both provide the community with competitive S&T tools for technical collection, technology that supports human collection, and the ability to assess the near and far term threat from the use of these capabilities against the US.

This is a rapidly evolving threat enhanced by the US participation, at every level, in the global marketplace. Accordingly I request the ISB respond within four months with analysis of this growing threat and recommended actions for the DNI to chart a course of action that is consistent with the pace of the threat.

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EXECUTIVE SUMMARY

> "Without the kind of intelligence which the CORONA program provided, the U.S. budget for the defense of our own territory, and for military assistance to our allies, would doubtless have been increased by billions." Worse, "**We might have misguidedly been pressured into a World War III.**"[1]

BACKGROUND

During the decades of the cold war U.S. science and technology (S&T) indisputably led the world and served as an essential enabler for the intelligence and military forces required to support our strategy of deterrence and containment. The world has changed significantly since then: deterrence and containment are tangential to the problems posed by terrorism and radical Islam, but intelligence and the other instruments of national power have not yet found the right alternative. The effort reported here focuses on one piece of this complex issue: **the impact on the Intelligence Community of the new global S&T landscape.**

Many studies have addressed the current and projected state of U.S. S&T compared to the rest of the world. An exhaustive report by the National Academy of Sciences, *The Gathering Storm*,[2] analyzes all aspects of U.S. research and development (R&D), from education to innovation and implementation. *The Gathering Storm* concludes that the United States still possesses the world's strongest science and engineering enterprise, but that other nations, both developed and developing, are challenging our preeminence. The rate at which the rest of the world is expanding its efforts to close the gap significantly exceeds our efforts to maintain that gap. That the United States probably continues to dominate in some or most traditional areas of S&T tends to mask the "rate of closure" and to obscure the near certainty that in some very important areas we will soon lose our historic lead. **This also calls into**

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[1] Kenneth E. Greer, "CORONA" (recently declassified version of 1973 report), in CIA History Staff, *CORONA: America's First Satellite Program* (Washington, DC: Center for the Study of Intelligence, Central Intelligence Agency, 1995), 38.

[2] National Academy of Sciences, Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, DC: National Academy of Sciences, 2006) [hereafter cited as *Gathering Storm*].

question whether "ahead" and "behind" even remain useful ways of viewing this subject and whether the United States can identify and adopt new ways to accommodate that reality.

While the overall effect of a declining S&T position on the United States remains the subject of debate, there can be no debate concerning its enormous impact on the Intelligence Community. Not only does it affect the Community's mission to develop new science-based tools that can meet dramatically changed collection needs, but it also makes it more likely that our adversaries can employ the very same—or perhaps even more advanced—S&T available to the United States. Today's collection and analysis needs, no longer driven by a policy of deterrence and containment, and the asymmetric capabilities of adversaries who are not necessarily nation-states, require an entirely new approach to increasing the contribution of S&T to the intelligence enterprise. Neither the Intelligence Community nor the S&T establishment has put forth viable strategies for accomplishing this change.

One of the principal enablers of the rapid worldwide diffusion of S&T is the ubiquitous Internet, combined with broadband access. It has been stated that the Internet is to the 21st century what the airplane was to the 20th century; except that it moves information rather than people and things and is available to anyone, anywhere at little or no cost. Information "processed" by people can lead to knowledge, which in turn can lead to applications enabling, for example, the incredible capabilities that our adversaries have exploited and used to further the goals of radical Islam. One of the greatest challenges facing the IC is to target, collect against, and assess such disruptive applications before they appear.

The changing nature of funding for U.S. R&D, from government to industry, poses a further complication for the Intelligence Community, as does the need for multinational collaboration to support research on such potentially disruptive capabilities as nanotechnology, life sciences including biotechnology, high-speed computing and telecommunications, quantum computing, and others. The government now has far less control than before over the problems addressed, the selection of personnel to perform the work, and the locations where the work is carried out, and less knowledge than ever before of *what* work is actually being done. Moreover, anyone, anywhere, can "log on" to see the results of the latest worldwide S&T investments.

This concern extends beyond "high technology," such as satellites and stealth. It encompasses a fundamentally changed mission and the associated, entirely new collection and analysis needs. The terrorist threat resembles a metastasized cancer that has spread through the world body. Just as early detection and new medical advances for locating, differentiating, and destroying cancer cells without collateral damage to critical organs are the tools for defeating cancer, precisely targeted intelligence represents the best way to combat spreading terrorism. Collection and aggregation of *granular* data provide the key to both tactical *and* strategic intelligence products and activities that can enable the intelligence profession to accomplish its new missions. The necessary granularity may reside more in the world of "open source" information than it does in the classified realm. Thus, increasing the synergy between the Intelligence Community and the worldwide community of scientists and technologists has become imperative.

The forces and trends involved extend well beyond the scope of the Intelligence Science Board (ISB). However, the ISB's responsibilities include generating transformational ideas focused on the Intelligence Community. This report addresses ideas previously suggested and recommends some newer approaches.

Discussion and Recommendations

In a recent series of addresses the Director of National Intelligence (DNI) announced plans to form an R&D program for the Intelligence Community that draws upon the lessons learned from the Defense Advanced Research Projects Agency (DARPA). **We enthusiastically support the iARPA concept, but urge the DNI to establish the program in a manner that maximizes the probability of success.** The right to fail, professional technical management, and adequate resources of both staff and money gave DARPA the chance to succeed. These same elements—especially the right to fail, availability of resources, and the *time* to try and try again—are the key ingredients of successful human intelligence (HUMINT). Unless they are also key elements of an S&T effort that will enable the new HUMINT we now so desperately require, iARPA cannot succeed. **More specifically, if iARPA simply combines existing programs, all of which lack adequate staffing and finances, it will maximize the probability of failure, not success. That legacy would have agonizing consequences.**

As recommended by *The Gathering Storm* in connection with an ARPA program for the Department of Energy, the Intelligence Community's iARPA program will need a rotational staff. We recommend that half of this staff come from the private scientific community and half from the Intelligence Community. Staff assignments should last no less than two years or more than four years. This constant infusion of new talent and new ideas would yield obvious benefits to the Intelligence Community. Like DARPA, iARPA should also be a multilevel security program.

Finally, and just as critical, **we urge the DNI to exercise his reallocation authorities and ensure that iARPA is funded at a minimum of double the level of the existing organizations that are being transferred into this new program.** This would make discretionary funding available for new ideas and for longer term programs,[3] and avert poaching on programs already underway. Without this level of funding, without the expectation that failures will outnumber successes, and without an integrated mix of talented personnel from within and outside the Intelligence Community who are experienced across collection and analysis, the new enterprise will simply replicate what already exists: do what we have always done, get what we have always gotten.

If the Intelligence Community is to compete and perform its expanded mission it must take risks, assess those risks, and continually measure their impact. We cannot continue to keep the best and brightest in limbo until they receive their highest level clearance and then put them into the electronic isolation-like atmosphere of the current Intelligence Community organizations. It is remarkable how many people in the community recognize this and how many people are unable to do anything about it. We strongly urge the DNI to mandate changes in current business practices that inhibit the hiring and effective use of the best and brightest analysts, collectors, and linguists, especially at the entry level. Heroic efforts have begun, but transformation—not evolution—is needed. When accepted for employment candidates should be put to work in a multilevel security environment that permits them to contribute immediately and—most important—allows them to use the information technology tools available to the rest of the world.

The current system uses intermediaries who collect, synthesize, and feed their own conclusions to those who write assessments. That

[3] Recall that in the CORONA program launch after launch—eleven in all by May 1, 1960, eight of which carried cameras—resulted in failure. The only variation was in the cause.

approach lowers the quality of assessments and fails to empower analysts with fundamental understanding of the subjects for which they are responsible.

The new global environment can confer certain advantages: there are probably more Americans now employed in multinational corporations in foreign and domestic companies than ever before. The Intelligence Community needs a better way to collect from them. Because the range is so great, and the talent within the Intelligence Community available to exploit these opportunities so overextended, we must first "triage" those areas where new, innovative, and direct interaction by analysts would likely have greatest impact against the highest priority target areas. Thereafter, traditional collectors and analysts together must find new ways to ensure the most effective and direct interaction with this important source of S&T insight outside the United States. Similarly, Intelligence Community analysts cannot directly access existing collaboration networks that include foreign experts—government, academic, and retired. We must change the rules and permit our analysts to participate, either openly or anonymously, if they are truly to understand other cultures and their uses of S&T.

Much of what we recommend involves change, but change implies risk. More than ever in the past, pervasive risk aversion severely hobbles innovation in the Intelligence Community. The dramatic change in the nature of the threat and the potential adversaries we face compounds this problem to critical levels. Unless the Intelligence Community leadership can break through and create a realistic risk management approach to such issues as increasing direct analyst involvement in the most important areas of private sector S&T expertise, the Intelligence Community will have wasted its efforts. **Leadership is the answer, and that leadership, that "permission" to take measured risk, must come from the DNI.**

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1. INTRODUCTION

In recent years, numerous reports have sounded the alarm regarding U.S. competitiveness in science and technology (S&T). According to the United States Commission on National Security/21st Century:

> Americans are living off the economic and security benefits of the last three generations' investment in science and education, but we are now consuming capital. Our systems of basic scientific research and education are in serious crisis, while other countries are redoubling their efforts. In the next quarter century, we will likely see ourselves surpassed, and in relative decline, unless we make a conscious national commitment to maintain our edge. We also face unprecedented opportunity. The world is entering an era of dramatic progress in bioscience and materials science as well as information technology and scientific instrumentation. Brought together and accelerated by nanoscience, these rapidly developing research fields will transform our understanding of the world and our capacity to manipulate it.
>
> The United States can remain the world's technological leader if it makes the commitment to do so. But the U.S. government has seriously underfunded basic scientific research in recent years. The quality of the U.S. education system, too, has fallen behind those of scores of other nations. This has occurred at a time when vastly more Americans will have to understand and work competently with science and math on a daily basis.
>
> In this Commission's view, the inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine. American national leadership must understand these deficiencies as threats to national security. If we do not invest heavily and wisely in rebuilding these two core strengths, America will be incapable of maintaining its global position long into the 21st century.[4]

This report by the Intelligence Science Board analyzes the challenges this altered S&T landscape presents for the Intelligence Community (IC). It focuses on several key questions:

- How does this change affect the way the United States employs S&T to meet its national security goals?

[4] The United States Commission on National Security for the 21st Century, *Road Map for National Security: Imperative for Change* (Washington, DC, February 15, 2001), ix.

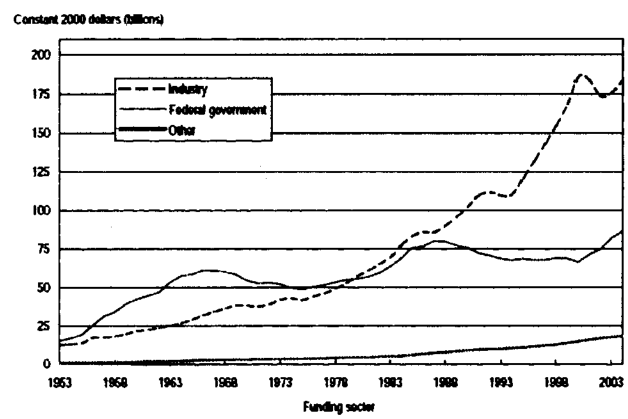
- How can the United States understand how others may employ S&T to our disadvantage?
- What does this altered landscape offer that the United States can exploit?
- How can the IC transform to meet this challenge?

In the next section we review broad-based indicators of the changing competitive landscape in general. Section 3 discusses some implications of this shift, with particular focus on particularly critical technologies, especially those being developed openly and collaboratively worldwide. In Section 4 we draw some conclusions from this background and then offer recommendations for beginning the process of adjusting to this new world. The Appendixes provide a more detailed description of worldwide S&T today and the trends for the future.

2. THE ALTERED LANDSCAPE

2.1 U.S. FUNDING FOR R&D

U.S. research and development (R&D) spending overall grew to $319.7 billion in 2005, growing 2.5 percent from 2004. It is projected that the 2006 data will show continued growth to $328.9 billion, largely due to investments by the business sector.[5] But while spending has continued to increase, the sources of funding and type of research conducted have shifted. Private industry funding for R&D overtook federal spending in 1979 (Figure 1). The federal share of R&D funding fell to a low of 24.9 percent in 2000, and then rebounded to a projected 29.9 percent as the business sector entered a slowdown and federal spending expanded, particularly in the areas of defense, health, and counterterrorism.[6] However, more recent budget figures indicate that funding for federal R&D in the FY2006 budget, after adjusting for inflation, would decline for the first time since 1996.



FFRDC = federally funded research and development center

NOTE: R&D data for 2004 are projections.

SOURCE: National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources (annual series).

Figure 1. U.S. R&D Spending by Funding Sector: 1953–2004

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[5] "2005 R&D Funding Forecast," *R&D Magazine*, January 2005, F3; "2006 R&D Funding Forecast," *R&D Magazine*, January 2006, F3.

[6] National Science Board, *Science and Engineering Indicators 2006,* Volume 1 (Washington, DC: National Science Foundation, February 23, 2006), 4–5, http://www.National Science Board.gov/statistics/seind06/

This development has significant implications for advancing R&D. In essence, it has meant that control over the types of research conducted has moved to the private sector. Because federal and industry funds tend to be used for different types of R&D, this shift between business and federal spending has meant a decline in the basic research and a concomitant increase in shorter-term, more applied research (Figure 2). Moreover, the government now has far less control than before over the problems addressed, the selection of personnel to perform the work, and the locations where the work is carried out, and less knowledge than ever before of *what* work is actually being done. Anyone, anywhere, can "log on" to see the results of the latest worldwide S&T investments.

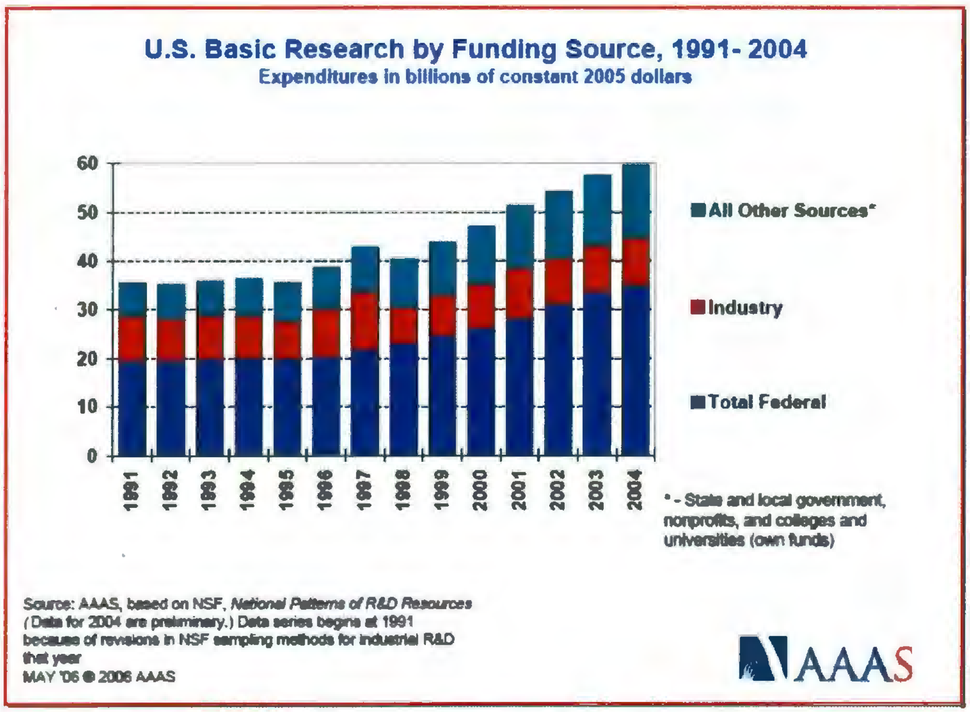

Figure 2. U.S. Basic Research by Funding Source 1991–2004

Most basic research[7] is funded by the federal government and is performed at universities and colleges. The majority of the support—59 percent—went to the life sciences, while the shares devoted to engineering and the physical sciences declined. The primary increases in recent years occurred in biomedical research conducted by the National

[7] Basic research is work "undertaken to gain knowledge and understanding of the fundamental aspects of nature." Congressional Research Service [CRS], *Science and Technology Policy: Issues for the 109th Congress* (Washington, DC, February 2006, updated September 1, 2006), 1.

Institutes of Health (NIH). However, in the FY2006 budget, most of the growth was attributable to increases in defense weapons systems and the National Aeronautics and Space Administration's human space exploration technology program.[8] However, basic research has declined as a proportion of federal funding.

Academic institutions have become increasingly reliant on federal funds for supporting their research programs. This becomes significant in view of the characteristics of the faculty members who actually conduct the research, many of whom are foreign born (see Section 2.2.2).

Purely developmental activities directed toward the creation of new goods, services, and processes are primarily funded by industry and constitute the majority of industry R&D spending (Figure 3). Thus, as support for U.S. R&D has shifted from federal funds to industry funds, the amount of money spent on long-term basic research has remained relatively flat, while spending on short-term developmental projects has increased substantially. In 2003, over one-third of all industry-funded R&D was concentrated in the computer and electronic products industry and computer-related service companies.[9]

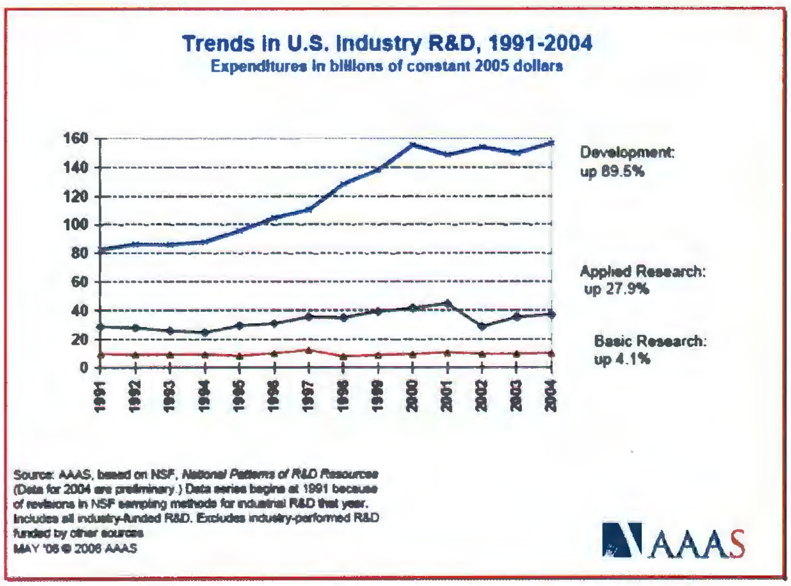

Figure 3. Trends in U.S. Industry R&D, 1991–2004

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[8] *Ibid.*, 2.

[9] National Science Board, *supra*, 4–5.

2.2 GLOBAL TRENDS

Meanwhile, foreign investment in R&D has been growing at a greater pace than U.S. R&D. The National Academy of Sciences Committee on Prospering in the Global Economy of the 21st Century stated in their report that "having reviewed the trends in the United States and abroad, the committee is deeply concerned that the scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength."[10] Others have suggested that the problem is not so much that the United States is in decline but rather that others

> ...are advancing quickly from behind, putting all their economic resources into moving their countries forward. The problem is that even if the United States were doing everything right, the world still poses an unprecedented competitive challenge. Unfortunately we are not doing everything right, and this compounds the challenges that we face.[11]

Statistics for Organisation for Economic Cooperation and Development (OECD) and nonmember economies show that the 1995–2003 average annual growth rate of 17.1 percent for eight non-OECD members contrasted sharply with the 5.6 percent annual growth for OECD members (Figure 4).

Industry is also increasingly looking beyond national borders as it decides where to locate R&D activities. Foreign-owned companies and foreign-born inventors now account for nearly half of U.S. patents.12 The global nature of S&T markets is also reflected in the rising number of corporate international alliances devoted to joint R&D or technology development. The number of new international alliances rose from under 100 in 1980 to 342 early in the twenty-first century. These multinational corporations and organizations compete against or even overshadow national entities and interests, which can result in the blurring of distinctions between government and commercial goals.13 Moreover, existing mechanisms to identify foreign membership, control, or

[10] *Gathering Storm*, 2.

[11] *2005 Report to Congress of the United States-China Economic and Security Review Commission* [hereafter cited as China Commission] (Washington, DC, November 2005), citing testimony of William Archey, 94, http://www.uscc.gov/annual_report/2005/05annual_report_contents.htm

[12] National Summit on Competitiveness, Statement: "Investing in U.S. Innovation," December 6, 2005, 1, http://www.mep.nist.gov/competitiveness-innovation.pdf .

[13] Counterintelligence in a Time of Rapid Change: The Impact of Technology and Globalization, June 26, 2006.

influence over U.S. firms whose work is vital to U.S. defense and intelligence systems have proven inadequate to keep up with the rapid changes in ownership, control, and influence.14

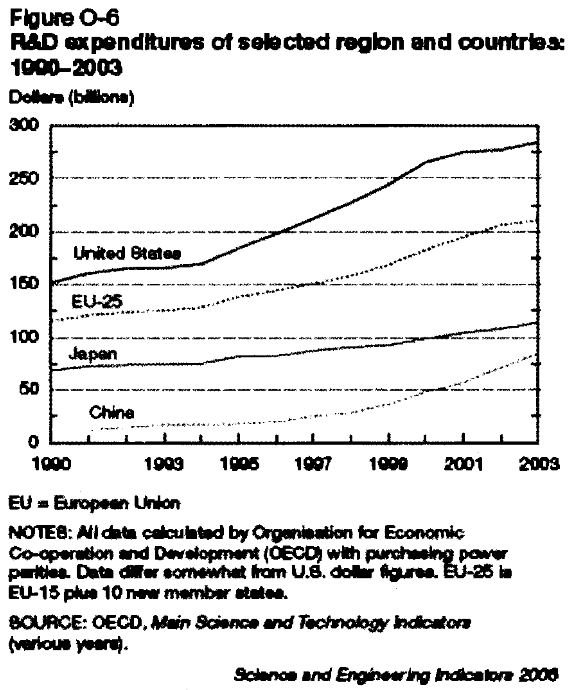

Figure 4. R&D Expenditures of Selected Regions and Countries, 1990–2003

Europe remains the single largest location of overseas R&D expenditures, but R&D expenditures in Asia by U.S.-based multinationals more than doubled to about $3.5 billion in the region. This increase was fueled primarily by steep investment growth in China and the Asia-8 economies.[15]

Average annual increases in R&D investment from 1991–2003 ranged from 4 percent to 5 percent for the United States, EU-25, and Japan. These contrasted sharply with the 17 percent average annual growth for China, and this rate is accelerating: for the past five years, China's R&D expenditures have registered 24 percent average annual increases. Even if more fully comparable Chinese figures reduced the growth statistics

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[14] U.S. Government Accountability Office [GAO], *Industrial Security—DOD Cannot Ensure Its Oversight of Contractors under Foreign Influence Is Sufficient*, GAO Report GAO-05-681 (Washington, DC, July 2005), http://www.gao.gov/new.items/d05681.pdf

[15] *NSF, Science and Engineering Indicators, 2006*, O-5.

somewhat, such a rapid advance in comparison to the leading R&D-performing countries and regions would still be unprecedented in recent history.

The increase in spending is complemented by the growth in China's industrial research workforce, which expanded from 16 percent of the size of its U.S. counterpart in 1991 to 42 percent in little more than a decade.[16] The United States-China Economic Security and Review Commission (China Commission) found that

> Science and technology (S&T) development is the centerpiece of China's comprehensive strategy to build national power. As a result, the Chinese government has a comprehensive, coordinated strategy for S&T development, which it began to implement in the mid 1980s with the 863 program. This strategy translates into government policies to encourage growth and investment in key industries, among which are software and integrated circuit industries. Such policies include foreign investment incentives, tax incentives, government subsidies, technology standards, industrial regulations, and incentives for talented Chinese students studying and working overseas to return to China. Many of these policies make it difficult, if not impossible, to achieve a level playing field in this area of U.S.-China trade and jeopardize long-term U.S. leadership in this vital sphere.[17]

The Commission noted further that, "Attracting U.S. and other investment into China has been an important component of this strategy, particularly where transfers of technology and know-how have accompanied this investment."[18]

New industrial technology alliances worldwide reached an all-time peak in 2003. In addition, many high-tech companies have begun to locate major research installations outside the United States. Most notable is the dramatic increase in foreign investment in China: by mid-2004 the Chinese government had registered over 600 such facilities, many belonging to large, U.S.-based multinationals.[19] In 2003 China cited a *Fortune* survey showing that over 92 percent of multinational corporations will consider setting up regional headquarters in China in the future.[20]

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[16] National Science Board, *supra*, O–6.
[17] China Commission, *supra*, 86.
[18] *Ibid.*, 85.
[19] Richard Freeman, "Does Globalization of the Scientific/Engineering Workforce Threaten U.S. Economic Leadership?," Working Paper 11457, National Bureau of Economic Research, June 2005, 9.
[20] http://au.china-embassy.org/eng/jmhz/t46221.htm

By contrast, the share of R&D sites based in the United States and in Western Europe has fallen over the last 10 years. Data about plans over the next three years for current R&D networks of surveyed companies reveal that almost all of the planned growth in foreign R&D will be in China and India,[21] which are about to overtake Western Europe as the most important locations where U.S. companies conduct foreign R&D.

Mere growth in sites does not tell the whole story, however. In China, a low-cost skill base is coupled with companies' need for market and customer access, which suggests that companies are focusing less on large innovation gains in China than in India or Eastern Europe. Overall, foreign sites were found to be more likely "to focus on specific areas of expertise within the development process" and on customizing products for local markets. Indeed, the primary reason that companies cited for opening or increasing the size of new sites in China was to be closer to their customers. [22]

The China Commission found that the sophistication of the technology developed and produced by China is increasing at an unexpectedly rapid pace, and cautioned that China's approach to this development includes "aggressive use of industrial espionage."[23] It reports that China is using its large network of overseas researchers and students to acquire confidential scientific and technological information from foreign companies (see Section 2.2), and cites David Szady, the former chief of FBI counterintelligence operations, as saying that Chinese espionage efforts have helped the country attain technological developments that would normally take ten years but are only taking China two or three. Szady alleges that China's industrial espionage focuses on systems, materials, and designs and on "going after both the private sector, the industrial complexes, as well as the colleges and universities in collecting scientific developments that they need."[24] At the same time, the globalization and growth of multinational corporations and organizations is blurring the distinction between government and

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[21] China Commission, *supra*.
[22] *Ibid*., 6, 9.
[23] *Ibid*., 87. The Commission noted that as a result U.S. companies are taking some precautions with respect to their China operations. For example, it said Intel has not built a fabrication plant in China because it feared that it would lead to a transfer of proprietary information on its chip designs and also on the design and management of its manufacturing process. *Id*., citing Fred Vogelstein, "How Intel Got Inside," *Fortune*, October 4, 2004, 127.
[24] *Ibid*., 93, citing Damian McElroy, "China Aims Spy Network at Trade Secrets in Europe," *The Telegraph*, July 3, 2005.

commerce, making it difficult to distinguish between foreign-based corporate spying and state-sponsored espionage.[25]

The China Commission also noted that China is making significant progress in developing indigenous firms that have global brand recognition, reputations for producing quality products, and leading-edge R&D programs. China's growth strategy also involves developing different technology standards, which may act as a significant market access barrier to products made outside China.[26] Another commentator stated that Chinese leaders view science and technology as "a kind of warfare." China's progress "on the technology front" is seen as intimately connected to the global strategic balance.[27]

Assessing the actual level of technological development in China is difficult and subject to dispute. U.S. government assessments of China have traditionally assumed that China's technological development lags far behind that of the United States. While conceding that China has made "high-level breakthroughs" in nanotechnology, computer chip and semiconductor design, satellites, and supercomputing, "the federal government does not currently produce an assessment of the implications of these advancements for China's technological development as a whole or their application specifically to China's military advancement."[28] The China Commission pointed out that neither current National Intelligence Estimates on China nor the Department of Defense's (DoD's) annual report to Congress on China's military power contain an assessment of China's technological development.[29] The National Science Foundation (NSF) measures such development through various indicators such as the number of patents granted, the amount of funds U.S. parent companies invest in R&D affiliates in China, domestic gross expenditures for R&D, the number of science and engineering (S&E) degrees issued, and the percentage of high-technology exports. NSF concludes that, with the exception of the S&E degrees indicator, China's technological development is low relative to that of Malaysia, Taiwan, and South Korea. However, the rate of growth for these indicators in recent years is prompting the NSF to update its data on China. By contrast, a Korean

[25] Counterintelligence in the Time of Rapid Change: The Impact of Technology and Globalization, June 26, 2006.
[26] China Commission, *supra*, 90.
[27] Evan Feigenbaum, *China's Technowarriors* (Stanford, CA: University Press 2003), 1.
[28] China Commission, *supra*, 96.
[29] *Id.*

government assessment places China's technological development only 2.1 years behind Korea and 7.0 years behind the United States.[30]

Academic R&D has seen robust growth in many countries, as governments try to stimulate basic research capability and to connect universities with industry for the efficient exploitation of research results. The United States and the EU-25 (including 10 new member countries) have been spending similar amounts for academic R&D, $41 to $44 billion in 2003. Such spending remains less prominent in Asia, where R&D tends to focus more on applied research and especially on development. China has experienced the most rapid growth in its spending for academic R&D, but the academic sector plays a relatively small role (about 10 percent) in China's R&D system.

2.3. *EDUCATION OF SCIENTISTS AND ENGINEERS*

2.3.1 Worldwide Trends

Like the industrial sector, the education sector is becoming increasingly globalized. Today foreign students earn 30 percent of the doctoral degrees awarded in the United States and 38 percent of those in the United Kingdom. In the United States, 20 percent of newly hired professors in science and engineering (S&E) are foreign born, while the vast majority of newly hired faculty at the top research universities in China received their graduate education abroad.[31]

The number of first university degrees[32] awarded around the world is rising rapidly, from about 6.4 million in 1997 to 8.7 million in 2002. Among these, the largest proportion of these degrees are in S&E, but the share of S&E degrees in the United States (just under one-third) is lower than in other countries, as is the share of U.S. degrees in natural sciences and engineering (NS&E)—S&E degrees not including the social sciences and psychology. These statistics have held fairly steady over the years. They also reflect world trends: in 1997, an average of 44 percent of all

[30] *Ibid.*, citing Michael Pillsbury research and RAND report.
[31] Richard Levin, "Universities Branch Out: From Their Student Bodies to Their Research Practices, Universities Are Becoming More Global," *Newsweek*, August 21, 2006.
[32] According to the U.S. Department of Education's Institute for Education Sciences, "A bachelor's degree in the United States, the first university degree is typically of medium length (three to five years duration in the international classification). In Germany it is called the Diplom, in Italy the Laurea, and is generally a long degree (five to six years duration in the international classification)." See http://nces.ed.gov/surveys/international/IntlIndicators/glossary.asp

degrees awarded in other countries were in S&E, but that number fell to 38 percent in 2002. Similarly, the share of NS&E degrees in countries other than the United States declined from 30 percent to 27 percent.

The education of young people in NS&E has become increasingly important for many governments as they try to build more knowledge-intensive economies, and statistics vary widely for first university degrees in NS&E. The United States, with just under 6 percent, ranks 32nd out of the 90 countries for which data are available. China and India have low ratios (1.6 and 1.0, respectively), due to low overall rates of access to higher education in those countries, but China is strongly trending upward as production of S&E degrees in China doubled and engineering degrees tripled over the past two decades.[33][34]

The number of S&E doctorates internationally has also increased. In recent years most S&E doctorates (78 percent in 2002) were granted outside the United States. Approximately one-third of the engineering doctorates were awarded in Asia, where numbers are probably understated because of incomplete reporting. In 2002 the United States produced only 15 percent of the world's engineering doctorates, but even then students on temporary visas earned more than half of these degrees.

2.3.2 Foreign-Born Scientists and Engineers

The influx to the United States of scientists and engineers from other countries accelerated in the 1990s, and the number of foreign-born individuals holding U.S. S&E jobs increased sharply. By 2000, this share had increased from 14 percent to 22 percent (Figure 5). More than half of the engineers holding doctorates and 45 percent of doctorate holders in the physical sciences, computer sciences, and life sciences were foreign born: one-third of them coming from India, China, and the Philippines. Among doctorate holders, those from China and India alone comprised one-third of the total.

[33] National Science Board, *supra*, O-12.
[34] *Ibid.*, 12–13.

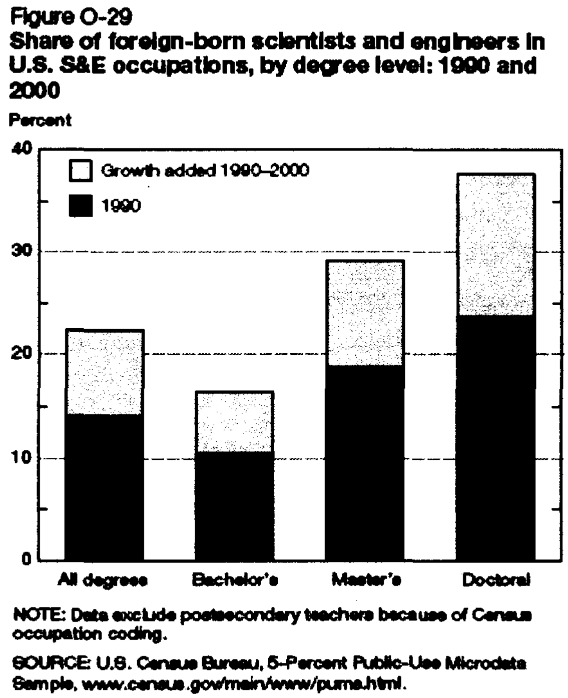

Figure 5. Share of Foreign-Born Scientists and Engineers in U.S. S&E Occupations, 1999–2000

Foreign students earned one-third of U.S. S&E doctorates and 55 percent of engineering doctorates, whereas the number of S&E doctorates earned by U.S. white males dropped sharply. The production of U.S. S&E doctorates since 1990 rose from 23,800 to a record 28,800 in 1998 before dropping to 26,900 in 2003. The overall number was strongly driven by the number of foreign students. Each year between 6,800 and 8,700 doctorates were awarded to students holding temporary visas: in 2003 these students earned one-third of the total number of doctorates, more than half of those in engineering, 44 percent of those in mathematics and computer science, and 35 percent of those in the physical sciences.[35]

Changes in U.S. visa policies after September 11, 2001, affected the flow of foreign-born scientists and engineers into the United States. The number of high-skill-related visas issued annually to students, exchange visitors, and others decreased sharply after September 11. Foreign

[35] The number of U.S. Asian students is inflated by the conversion of large numbers of Chinese students with temporary visas to permanent status under the 1992 Chinese Student Protection Act.

student visas are now recovering but remain down by one-fifth since 2001, while other high-skill visa categories are showing upward trends.[36]

Despite the recent downturns, foreign students earned one-third of U.S. S&E doctorates and 55 percent of engineering doctorates. In 2003 students holding temporary visas earned one-third of the total number of doctorates, more than half of the engineering doctorates, 44 percent of the mathematics and computer science doctorates, and 35 percent of the physical science doctorates.[37] Moreover, a growing number of graduate students, doctorate holders, and postdoctoral fellows chose to remain in the country for further study or work. Through 2003, 53 percent of the 1993 doctorate recipients were working in the United States in 1997 and 61 percent of the 1998 cohort had also remained in the country.

This influx of students and S&E professionals from Asia to the United States may not continue, especially since other countries are creating immigrant-friendly policies for those with advanced S&E degrees. Asian nations that have been the source of two-thirds of foreign doctoral candidates in the United States are now developing their own S&T infrastructures.

New approaches to conducting academic research across international borders may represent an even more interesting development. For example, a Chinese professor at Yale runs a research center focused on genetics of human disease at his alma mater, Shanghai's Fudan University, in collaboration with faculty from both schools. The Shanghai Center has 95 employees and graduate students working in a large laboratory facility. Yale faculty, postdoctoral fellows, and graduate students visit often and attend videoconference seminars with scientists from both campuses. The Yale-based laboratory is more productive due to the lower costs of conducting research in China, and Chinese graduate students, postdoctoral fellows, and faculty receive on-the-job training from a world class scientist and his U.S. team.[38]

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[36] National Science Board, *supra*, O-17.
[37] *Ibid.*, p. O-15–16.
[38] Levin, *supra.*

2.4 WORLDWIDE ACCESS TO INFORMATION

2.4.1 Broadband Access

The rapid expansion of broadband access, combined with the ubiquitous Internet, is the great enabler that extends the ability to collect and share information around the world in mere seconds. As of the first quarter 2006 the United States still led in total number of broadband subscribers with over 48 million. China was in second place with over 41 million, and Japan was in third place with 23 million subscribers. If the growth in the number of subscribers continues at its current rate, China is expected to pass the United States sometime next year, although this growth rate has slowed significantly in the past two quarters. Despite these current figures, however, China still lags the United States significantly in household penetration, with only 8.62 percent of households having Internet access.

Broadband access via cellular/mobile networks promises to increase the number of broadband subscribers. Although second-generation (2G) cellular/mobile networks are able to provide data connectivity equivalent to slow dial-up links, they are not sufficient to provide truly mobile broadband wireless access. Third-generation (3G) mobile networks and "2.5G" enhancements for existing networks are adequate to provide packet-based communications that can reach broadband speeds of 200 kbps or better.[39] High-speed downlink packet access (HSPDA), also known as 3.5G, will require only incremental upgrading as opposed to replacement costs of other new technologies.[40]

3G mobile data services are currently available in major metropolitan areas in Europe, Asia, and the United States, and the next versions of 3G technologies are likely to achieve "widespread metropolitan coverage" by the end of 2007. Because voice revenues are declining, companies are looking to data services to offset these lower earnings. As a result, they are motivated to invest heavily in their networks and improve the available services.[41]

[39] Burton Group, "Mobile Broadband Wireless Access: Make It Quick," (Midvale, UT, November 30, 2005), 4–5.
[40] CNET Asia, April 24, 2006.
[41] Paul DeBeasi, "Mobile Data Services: So Many Choices, So Little Time," telebriefing, Burton Group (Midvale, UT, July 2006).

Even newer technologies are expected to fuel the expansion of broadband access into increasingly remote areas. One such technology, WiMax (also known as fourth-generation wireless or 4G), is expected to provide broadband access in rural areas not currently served by hardwire access.[42] This technology has received recent boosts from industry investment, although it may face a significant cost challenge from 3.5G technology in locations that have already invested in 3G infrastructure. Some question whether 4G technology will succeed, given the expense of building such wireless networks and the relative cheapness of fixed-line access. But other countries are investing heavily, notably Japan, where the government has made leadership in 4G "a national goal" and is investing millions of dollars in research.

The primary demand may come from countries where this technology will be the first to offer broadband access to remote areas rather than replacing existing technology. One source has indicated that the IEEE 802.16 2004 version of WiMax "is being adopted by carriers in developing countries as their primary means for providing broadband services, by competitive carriers globally to penetrate new markets, and by large incumbent carriers to extend their broadband networks into rural areas."[43] A further effort that will push broadband access to more remote areas is the development of a windup laptop that will cost only $100 to manufacture. This machine will only be sold to governments in developing countries for distribution to their nation's children.[44]

2.4.2 Cellular Telephones

The significant increase in mobile telephone penetration around the world parallels the rapid expansion of broadband and its supporting networks. The greatest impact of cell phone growth is being seen in countries where landlines were never installed in significant regions and where installing them would be prohibitively expensive.[45] As of December 2005, more than 2 billion people had cell phones. It is estimated that there will be 3 billion cell phone users worldwide by end of 2008; China alone is expected to reach the 600 million mark by 2009.

[42] WiMax stands for Worldwide Interoperability for Microwave Access and is based on IEEE 802.16e.
[43] "Broadband Strategies for the Fixed Market," report abstract, June 1, 2006, available at www.marketresearch.com/map/prod/1300373.html
[44] "$100-laptop Created for the World's Poorest Countries," NewScientist.com News Service, November 17, 2005, http://www.newscientisttech.com/channel/tech/dn8338-100laptop-created-for-worlds-poorest-countries.html
[45] "Mobile Phone Proliferates, A Hallmark of New India," *New York Times*, September 15, 2006, C-4.

Despite the rapidly changing nature of the cellular telephone industry, R&D spending by the telecommunications giants fell between 2000 and 2004, the latest year for which data were available. The drop in spending by these companies is expected to continue at least through 2006.

Despite the falling R&D spending cell phones can now provide an increasing number of services that extend well beyond voice communication, to include text messaging, FM radio reception, satellite positioning, and video recording.[46] These new devices are at the intersection of three key industries: communications devices, computers, and consumer electronics, and are the best-selling devices in all three of these categories.

Traditionally a few vertically integrated companies such as Nokia, Motorola, and Ericsson dominated the industry. In recent years barriers to entry have fallen, resulting in a completely new industry structure that involves many smaller firms, many of which design as well as build handsets. The largest of these original design manufacturers (ODMs) are located in Taiwan, China, and South Korea. The rise of ODMs has meant that, for example, Motorola and Sony Ericsson outsource 35 percent of their manufacturing and no longer design their own radio chips.[47]

2.4.3 Internet Standards

Standards for Internet use are also undergoing change. The next generation of the Internet Protocol, IPv6, is gaining momentum in South Asia and will be supported in Windows Vista. The new protocol will provide a greater supply of Internet addresses, improved configuration capabilities, mandatory support for IP security and quality of service, and simpler merging of networks. At a meeting of the Open Source Intelligence Forum in October 2006, Major General (ret.) Dale Meyerrose, chief information officer of the Office of the Director of National Intelligence (ODNI), stated that "the DoD and ODNI published a joint strategy to move to Internet Protocol version 6 in June. Additionally, Defense modified a number of its contracts, specifically those around net-centric services, so ODNI could use them more easily."[48]

Although operators in Asia have been ordered to support IPv6, U.S. IT managers have not acted to adopt the standard. Some have suggested

[46] "Battling for the Palm of Your Hand," *The Economist*, April 29, 2004.
[47] *Id.*
[48] Jason Miller, "Intel IT Is Coming Together," *Washington Technology*, October 20, 2006.

San Diego. Huawei has little transparency in its governance and ownership structure, but clear ties to the Chinese government and military, with significant Chinese government funding/credit.

Huawei has seen significant growth in market share in many critical areas of the Internet and telecommunications. The company reaches over 100 countries, works with 28 of the top 50 telecommunications operators, and services over one billion subscribers (Figure 6). A report by Heavy Reading, a market research firm,[50] found that Huawei ranked eighth among wireline-equipment suppliers, up from 18th last year (Cisco ranked first). Most strikingly, Huawei ranked fourth in service and support. The report calls Huawei's ascendancy "astounding" and says it has already surpassed several established vendors in perceived market leadership. Table 1, taken from the report, illustrates the extraordinary impact that Huawei already exerts on the market.

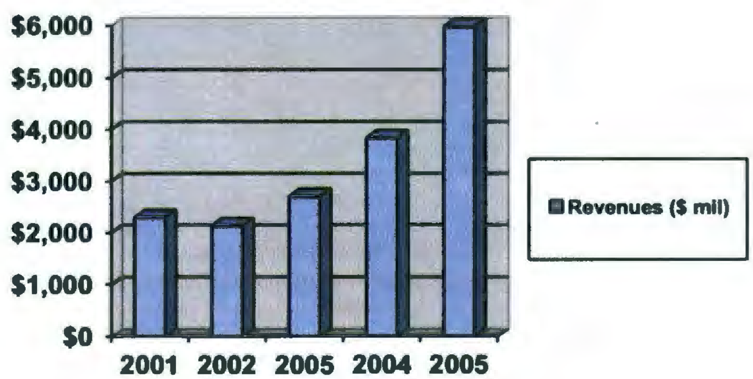


Figure 6. Huawei Revenues

Huawei's regional presence includes 39 Sub-Saharan countries, and offices in 13 Asia-Pacific countries and 11 Latin American countries. Huawei is the largest CDMA total solutions provider in the Middle East and the North Africa region, and has a North American subsidiary, FutureWei, located in Plano, Texas.

[50] Scott Clavenna, *Remade in China: Huawei and the Future of the Global Telecom Market*. Summary available on line at http://www.heavyreading.com/details.asp?sku_id=1160&skuitem_itemid=939&promo_code=&aff_code=&next_url=%2Fdefault.asp%3F

Table 1. Huawei's Market Presence

Service	Penetration
Wireless Terminal	• Product sales grew over 100% in 2005. • Markets data cards for cell phones and other wireless equipment via Vodaphone. • Markets handsets in Europe, Latin America, and Asia via partnerships with Vodaphone, Tata, and other equipment makers.
Wireless Network	• Mobile service product market share has doubled in each of past three years. • Reaches 140 million subscribers worldwide via partnerships with 22 of top 50 mobile carriers, including Vodaphone, Orange Group (France Telecom), and Royal KPN (Netherlands). • Largest global soft switch equipment supplier, servicing over 50 million subscribers in 40 countries. • Developing TD-SCDMA with Siemens.
Fixed Network	• Largest NGN provider in the global VoIP market, with 29.3% market share in terms of port shipments (Dittberner, 3Q05). • Largest provider in the global IP DSLAM market, with 32% market share (Infonetics, 3Q05). • Largest provider in global MSAN market, with 32.3% market share in terms of port shipments (Infonetics, 3Q05). • Second largest provider in the global DSLAM market, with 16.9% market share. • Products being adopted by many carriers in Western Europe.
Optical Network	• Largest provider in global long-haul DWDM market, with 15.9% market share. • Second largest provider in the global optical network market, with 10.3% market share. • Emerging as a mainstream equipment vendor to major carriers in Asia and Western Europe. • Currently expanding into Russia, Brazil, Romania, and Saudi Arabia.
Data Communications	• Products deployed in 91 countries, including UK, Germany, Spain, Russia, Singapore, and South Korea. • Third largest provider in global carrier Ethernet switch/router market, with 7% market share (after Cisco, 53%; Alcatel, 19%; and Lucent, 5%) (2Q06).

Source:
http://www.heavyreading.com/details.asp?sku_id=1160&skuitem_itemid=939&promo_code=&aff_code=&next_url=%2Fdefault.asp%3F

3. IMPLICATIONS: CHALLENGES AND OPPORTUNITIES

The National Security/21st Century Commission's stress on communicating the scale and pace of change has been borne out by extraordinary developments in science and technology since the Phase I report appeared.

- The mapping of the human genome was completed.
- A functioning quantum computing device was invented.
- Organic and inorganic material was mated at the molecular level for the first time.
- Basic mechanisms of the aging process have been understood at the genetic level.

Any *one* of these developments would have qualified as a "breakthrough of the decade" a quarter century ago, but they *all* happened within the past eighteen months (as of October 2006). This suggests the possible advent of a period of change whose scale will often astound us.

The key factor driving change in the U.S. national security environment over the next 25 years will be the acceleration of scientific discovery and its technological applications, and the uneven human social and psychological capacity to harness them. Synergistic developments in information technology, materials science, biotechnology, and nanotechnology will almost certainly transform human tools more dramatically and rapidly than at any time in human history.

3.1 RESEARCH AND DEVELOPMENT

The internationalization of both scientific research and its commercial development will have a significant impact on the United States' ability to harness S&T for the advancement of national security. U.S. strategy must create a balance between two key aims. The strategy must seek ways to reap the benefits of a more integrated world in order to extend freedom, security, and prosperity for all people. At the same time, it must strive to dampen the forces of global instability so that those benefits can endure and spread.

> The Department of Defense has come to rely on the private sector for certain technology developments, while the private sector is moving offshore much of its industrial and technology production and some of its technology design and research and development. This is taking place concurrently with China's growing position at the center of the technology supply chain, raising the prospect of future U.S. dependence on China for certain items critical to the U.S. defense industry as well as vital to continued economic leadership.[51]

For example, the DoD's "trusted" and "assured" supply of high-performance microchips is in jeopardy due to the restructuring of the U.S. commercial integrated circuit industry, which has moved operations offshore to Taiwan, Singapore, and China.[52] Other leading U.S. science and engineering institutions are following suit: even the Massachusetts Institute of Technology has established an outpost in China.

The rapid global expansion and technical convergence of digital communication systems means there will be widespread deployment of advanced technologies that allow almost any player—not only national intelligence services—to communicate relatively securely. This also increases the possibility that U.S. operations may be discovered and compromised, while new technologies such as commercial encryption, VoIP applications, or advanced monitoring and intercept systems permit heightened internal defenses against U.S. collection efforts.[53] Because industry now dominates R&D so strongly, these new tools and technologies are entering the global consumer market before the Intelligence Community can fully appreciate and/or compensate for their intelligence and counter-intelligence impact.[54]

The length of time required to exploit particular U.S. innovations is also shortening significantly. Joint ventures, partnerships, and foreign-owned U.S.-based subsidiaries can offer foreign interests easier access to sensitive U.S. technology and information. As rapidly as the United States develops and installs new tools to protect borders, weapons, data, or intelligence, our adversaries are developing new ways to defeat them or to use them for their own purposes.[55]

Globalization thus complicates efforts to ensure that critical national security and defense equipment and software are built, maintained, and

[51] China Commission, *supra*, 85.
[52] *Ibid.*, 97.
[53] *Id.*
[54] *Id.*
[55] *Id.*

supported by appropriately vetted and cleared U.S. firms and personnel. As economic and political pressures drive the U.S. government and U.S. firms to take on foreign partners or outsource work to foreign firms it is becoming more difficult to control access to sensitive information. At the same time, however, globalization offers opportunities if the Intelligence Community can exploit it and technological competition to provide new possibilities for recruiting sources, collaborating with researchers to prevent technological surprise, and working judiciously with close partners to leverage scarce resources and intelligence to achieve common goals.[56]

3.1.1 Disruptive Innovations

Certain innovations have the potential to alter fundamentally the way the Intelligence Community and its partners operate around the globe. These innovations will have broad implications, from accelerating information transfer to affecting the ability to operate in secret to altering the balances of economic and political power. To build a strategy to deal with these innovations, the Intelligence Community must understand the U.S. position in each of these fields and how these impacts may play out.

A study by RAND for the National Intelligence Council attempted to address the feasibility of many of these innovations. Table 2 lays out the conclusions. The letter "G" in parentheses after the item indicates that these items are expected to have a global impact.

[56] Counterintelligence in the Time of Rapid Change: The Impact of Technology and Globalization, June 26, 2006.

Table 2. Technical and Implementation Feasibility of Illustrative 2020 Technology Applications

Table S.1
Technical and Implementation Feasibility of Illustrative 2020 Technology Applications

Technical Feasibility	Implementation Feasibility: *Niche market only* (– –)	*May satisfy a need for a medium or large market, but raises significant public policy issues* (–)	*Satisfies a strong need for a medium market and raises no significant public policy issues* (+)	*Satisfies a strong need for a large market and raises no significant public policy issues* (+ +)
Highly Feasible (+ +)	• CBRN Sensors on ERT (2,G)	• Genetic Screening (2,G) • GM Crops (6,M) • Pervasive Sensors (4,G)	• Targeted Drug Delivery (5,M) • Ubiquitous Information Access (6,M) • Ubiquitous RFID Tagging (4,G)	• Hybrid Vehicles (2,G) • Internet [for purposes of comparison] (7,G) • Rapid Bioassays (4,G) • Rural Wireless Comms (7,G)
Feasible (+)	• GM Animals for R&D (2,M) • Unconventional Transport (5,M)	• Implants for Tracking and ID (3,M) • Xenotransplantation (1,M)	• Cheap Solar Energy (10,M) • Drug Development from Screening (2,M) • Filters and Catalysts (7,M) • Green Manufacturing (6,M) • Monitoring and Control for Disease Management (2,M) • Smart Systems (1,M) • Tissue Engineering (4,M)	• Improved Diagnostic and Surgical Methods (2,G) • Quantum Cryptography (2,G)
Uncertain (U)	• Commercial UAVs (6,M) • High-Tech Terrorism (3,M) • Military Nanotechnologies (2,G) • Military Robotics (2,G)	• Biometrics as sole ID (3,M) • CBRN Sensor Network in Cities (4,M) • Gene Therapy (2,G) • GM Insects (5,M) • Hospital Robotics (2,M) • Secure Video Monitoring (3,M) • Therapies based on Stem Cell R&D (5,M)	• Enhanced Medical Recovery (3,M) • Immunotherapy (2,M) • Improved Treatments from Data Analysis (2,M) • Smart Textiles (4,M) • Wearable Computers (5,M)	• Electronic Transactions (2,G) • Hands-free Computer Interface (2,G) • *In-silico* drug R&D (2,G) • Resistant Textiles (2,G) • Secure Data Transfer (2,M)
Unlikely (–)	• Memory-Enhancing Drugs (3,M) • Robotic Scientist (1,M) • Super Soldiers (2,M)	• Chip Implants for Brain (4,M)	• Drugs Tailored to Genetics (2,M)	• Cheap Autonomous Housing (6,G) • Print-to-Order-Books (2,G)
Highly Unlikely (– –)	• Proxy-bot (3,M) • Quantum Computers (3,M)	• Genetic Selection of Offspring (2,M)	• Artificial Muscles and Tissue (2,M)	• Hydrogen Vehicles (2,G)

NOTE: For each technology, the parenthetical information indicates the number out of 12 societal sectors (water, food, land, population, governance, social structure, energy, health, economic development, education, defense and conflict, and environment and pollution) that can be impacted by the technology, and if the diffusion will be global (G) or moderated (M). For example, Hybrid vehicles affect two sectors and will have global diffusion.

Source: Richard Silberglitt, et al., *The Global Technology Revolution 2020, In-Depth Analyses*, RAND, 2006, p. xix

3.1.1.1 Nanotechnology

One field of particular interest is nanotechnology, which "...touches upon a broad array of disciplines, including chemistry, biology, physics, computational science, and engineering. Like information technology, nanotechnology has the potential to impact virtually every industry, from aerospace and energy to healthcare and agriculture."[57]

In 2005, worldwide spending for nanotechnology across all sectors totaled $9.5 billion, up 10 percent from 2004. Virtually every country that provides financial support for science and technology R&D has a nanotechnology initiative. Of the $4.6 billion spent by governments on nanotechnology R&D in 2004, the United States led in absolute terms, but Asia as a whole now spends as much on nanotechnology as the United States does. The trends incontrovertibly show significant increases in spending by all nations, particularly since 2000.

Roughly two-thirds of U.S. federal funding for the National Nanotechnology Initiative (NNI) flows to university researchers.[58] Although these programs may have a significant impact on the future of nanotechnology in the United States, that impact is not easily captured in traditional government/industry spending measures.

In reality, however, U.S. government spending is not keeping up with opportunities. The current administration's FY 2006 budget proposed a decrease in funding from the level of support provided by Congress in FY 2005.[59] The 2007 budget request is also less than the estimated 2006 spending. Thus, the U.S. figures over the next few years may show a decline, while foreign spending is expected to continue to rise. Researchers reported in 2005 that NSF received 48 proposals in its most recent solicitation for Nanoscale Science and Engineering Centers, but could fund only 6.[60]

Just as is true of overall S&T expenditures, the private sector, not government, accounts for the majority of nanotechnology spending in the

[57] President's Council of Advisors on Science and Technology [PCAST], *The National Nanotechnology Initiative at Five Years: Assessments and Recommendations of the National Nanotechnology Advisory Panel* (Washington, DC, May 2005), 5.
[58] Neal Lane and Thomas Kalil, "The National Nanotechnology Initiative: Present at the Creation," *Issues in Science and Technology*, Summer 2005, http://www.issues.org/21.4/lane.html
[59] *Id.*
[60] *Id.*

United States. The majority of corporate spending on nanotechnology R&D worldwide also occurred in the United States. A 2005 study identified approximately 600 companies in the United States or with significant U.S. operations that are engaged in nanotechnology R&D, manufacture, sale, and/or use.

While the United States spends more on an absolute basis for nanotech research than any other country, when spending levels are adjusted for purchasing power parity, the per capita spending in the United States is only fourth in the world.[61] In addition, some countries that the United States considers strategic threats, such as Iran, have nanotechnology programs. Experts agree that the trends indicate a "steady erosion" in the United States' lead in nanotechnology. Moreover, although other nations may not be spending as much as the United States overall, they are choosing to concentrate their efforts in particular sectors to make significant advances in those sectors more quickly. For example, as of 2005 it was reported that China had 3,000 researchers engaged in nanotechnology related programs and over 800 companies working in the nanotechnology field, and is concentrating strongly on development of nanomaterials. Chinese researchers are now publishing more research papers on nanotechnology, although one source suggests that the United States still has over 50 percent of the annual high-impact publications.

Sean Murdock, the executive director of the NanoBusiness Alliance, testified in June 2005 that currently the United States is leading the world in nanoscience, but the "lead is narrow and we face stiff and accelerating competition." He further argued that nanotechnology "will be a game changing technology" and is likely "to be the engine of innovation for the next fifty years." At the same hearing, Matthew Nordan of Lux Research, Inc., testified that while the United States leads the world in nanotechnology today "its position is tenuous." The President's Council of Advisors on Science and Technology reported in May 2005 that the trends in investment, publications, and patents all show a "steady erosion" in the United States' lead in nanotechnology.

Between 2001 and 2004 the U.S. share of global government spending on nanotechnology has dropped, even though the actual spending doubled from $465 million to $960 million (Figure 7). Although the United States spends more on an absolute basis for nanotech research than any other country, it is falling behind Asian countries on a relative

[61] *Id.*

basis. The $130 million in estimated government spending on nanotech in China equaled $611 million when adjusted for purchasing power parity—38 percent of U.S. expenditures. This placed China second, ahead of Japan and Germany. In addition, some countries that the United States considers strategic threats, such as Iran, have nanotech programs.

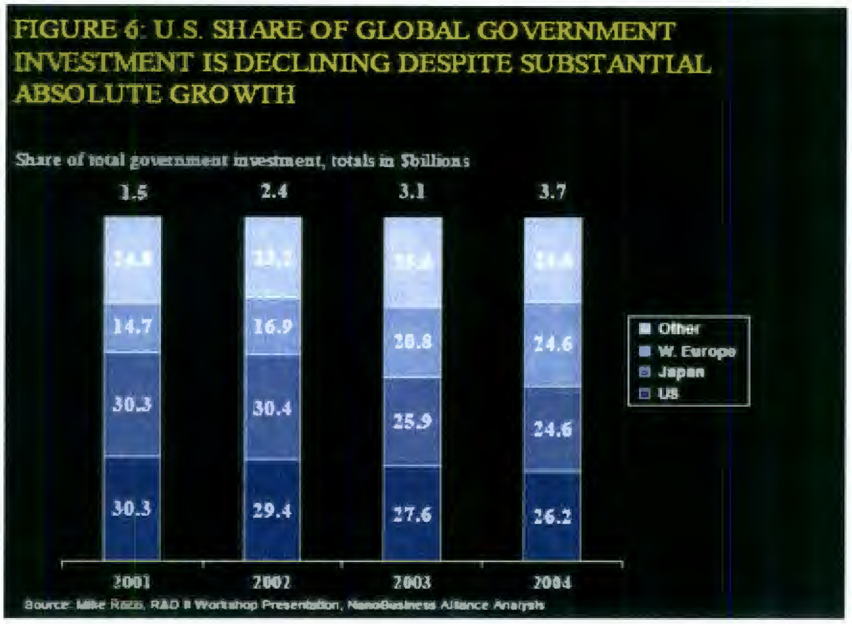


Figure 7. U.S. Share of Global Government Investment Is Declining

China recently promulgated its first standards related to nanotechnology and is currently seeking to develop a complete set of standards to be adopted by the International Standards Organization and thus shape the future of nanotechnological development. The United States, Japan, and some European countries are working on their own set of standards to try to create an alternative framework for the future direction of nanotechnology.

Some nanotech industry leaders express concern that China's lax enforcement of intellectual property rights makes competition with China difficult, if not impossible. Chinese manufacturers are stressing their ability to deliver products identical to those of U.S. and European companies at prices 15–20 percent lower. Because they generally refuse to identify their production processes, some suspect that they are using Western patent filings "like recipe books."[62]

3.1.1.2 Biotechnology

The development of biotechnology around the world is likely to be very uneven. For example, while Asian countries appear poised to move toward use of genetically modified foods and organisms, concerns over ethical issues and environmental risks are likely to pose a barrier to similar developments in the European Union.[63] The impossibility of containing knowledge within country borders as a result of the increasing flow of information, people, and resources means that cautious countries cannot control the actions of less cautious countries and/or entities. The emergence of significant private-sector investment around the globe for research in the areas of stem cells and cloning exemplifies this dilemma.

3.1.1.3 Quantum Computing

The Centre for Quantum Computation, a combined initiative by Cambridge and Oxford Universities, lists nearly 100 separate quantum computing research programs in universities, private industry, and international consortia in Asia, Europe, Asia, North America, Oceania, and South America. These program are developing the research foundations for this critical technology and sharing the results worldwide. The university programs attract and train the best students regardless of country of origin.

By contrast, many of the U.S. programs have the objective and maintaining the U.S. lead in this very competitive area. The openness and collaborative style of the research necessary to make advances are of critical importance to the IC, yet the U.S. programs lack these characteristics.

3.1.2 Observations

In its 2006 report *The Global Technology Revolution 2020, In-Depth Analyses,* which it prepared for the National Intelligence Council, the RAND Corporation reported that it saw "no indication that the

[62] *Id.*
[63] Richard Silberglitt, et al., *The Global Technology Revolution 2020, In-Depth Analyses* (Santa Monica, Calif.: The RAND Corporation, 2006).

accelerated pace of technology development is abating, and neither is the trend toward multidisciplinarity nor the increasingly integrated nature of technology applications." RAND also noted that many of the technological applications are controversial and that political considerations may affect their development in various countries. For example, countries show varying concerns regarding genetically modifying crops, genetically modifying insects, genetic screening for humans, gene therapy, and genetic selection of offspring. Other applications of technology have significant implications for privacy and personal freedom. Examples of these would be pervasive sensors, some uses of radio frequency identification (RFID) implants to track and/or identify individuals, chip implants in brains, and biometrics as the central means of personal identification.

The report notes that, in light of the

> ...accelerating pace of technology development and the rapid improvement of capacity to acquire and implement [technological applications] (TA) in emerging economies, maintaining country position in relative capacity to implement TAs will require continuing efforts to ensure that, for example, laws, public opinion, investment in R&D, and education and literacy are drivers for, and not barriers to, technology implementation. In addition, infrastructure needed for desired TAs must be built, supported, and maintained.[64]

It should also be noted that the United States cannot control the ethical, political, and/or economic environments in other countries that affect decisions regarding whether to invest in particular technologies. Thus, innovations that raise ethical, environmental, or political concerns for the United States may be developed in environments that do not share U.S. views. The growing dependence of U.S. academic institutions on federal research funds, coupled with the large proportion of foreign-born students and faculty members, raises additional questions.

3.2 Information Access

In the Internet age, information technologies may be used to empower communities and advance individual freedoms, but they can also empower political movements led by charismatic leaders with irrational premises and anti-democratic goals. Such men and women in the 21st century will be less constrained than those of the 20th by national

[64] *Id.*

boundaries, and less dependent on gaining large industrial capabilities to wreak havoc. For example, for an investment of as little as $50,000 a few people may manage to produce and spread a genetically altered pathogen with the potential to kill millions of people in a matter of months. Clearly, the threshold for small groups or even individuals to inflict massive damage on those they consider their enemies is falling dramatically.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

> We have led the world for decades, and we continue to do so in many research fields today. But the world is changing rapidly, and our advantages are no longer unique.[65]

The situations and trends summarized above, and described in greater detail in the Appendixes to this report, strongly support the conclusion that the forces of globalization and rapid access to information worldwide have profoundly changed the environment in which the IC must operate. They may significantly reduce the advantage the IC has enjoyed as the result of decades of U.S. dominance in S&T, and at the same time extend the development and benefits of leading-edge S&T to countries and actors inimical to U.S. interests. Not surprisingly, considerable informed debate surrounds the implications of this 21st century phenomenon and whether the diffusion of potentially important advances in S&T ultimately benefits or harms the United States. In the intelligence domain, however, we conclude unequivocally that this altered landscape threatens the S&T preeminence that the IC has relied upon—perhaps too complacently—since the formation of the modern Intelligence Community with the National Security Act of 1947. To safeguard U.S. national security, the IC must make fundamental changes in the way it operates within today's world of complex threats and potentially disruptive and revolutionary advances in S&T.

The IC must greatly improve its ability to assess the impact of S&T developments on the countries and non-state entities with which the United States competes, and over the full range of U.S. national security priorities. To do so, the IC must itself apply competitive S&T developments that enable collection and analysis in the broadest sense. Yet the IC is not taking full advantage of opportunities offered by the new, borderless world. For example, globalization means that more U.S. citizens, businesspersons, academics, and students than ever before are living or studying in foreign countries, or working for foreign-owned entities worldwide. There are more foreign-born people in with the United States with profound knowledge of the language and culture of

[65] *Gathering Storm.*

countries that the IC often can only read about. The IC needs to find better ways to tap both of these potential sources of information.

Similarly, we find that the IC fails to take full advantage of the enablers of the unprecedented diffusion of S&T: the Internet and broadband access. At present, the primary elements of the IC provide their staff with workplaces and tools that are simply inadequate to keep pace with the dynamic world environment.

We find that the "stovepipes" of S&T, analysis, and collection are, unfortunately, alive and well. Analysts task collectors for information they need. Collectors, in turn, use the tools at their disposal, including S&T enablers, to find what the analysts seek. This serial process is a relic of the Cold War that neither utilizes nor even recognizes the full scope of assets that S&T can and should provide, especially against the complex, "granular" threat that the IC confronts today. In the current environment, the IC must find and locate individuals who constantly move, delve into their motives and intentions, and understand far more about nations and non-nation state actors than it does now. It will take analysts, S&T experts, and collectors working together, not serially, to determine what S&T can offer to technical and human collectors and to analysts to meet IC needs. Just as important, only such a multidisciplinary team can recognize the limitations of current technology and determine the new S&T advances that the IC needs and should support.

We recognize the difficulties of making significant changes—transformational changes—in the IC: a set of widely disparate organizations whose successes are secret and whose failures are public. Change requires risk, and risk means accepting the possibility of such failures. Even so, many dedicated and innovative professionals recognize that the IC must break through the established stovepipe ways of doing business to a new, multidisciplinary model. They have kindled isolated "sparks" of change throughout the community. Unfortunately, we have every reason to believe that the forces of tradition will dominate and that those sparks will sputter and fade without encouragement by the highest level of leadership.

The following recommendations were inspired by these creative "sparks." At the very least, the IC should institute some or all of them in an experimental fashion and evaluate their effectiveness in helping U.S. intelligence to adapt better to today's challenging world. **This cannot**

occur in any meaningful way, or in a relevant timeframe, without the direct and active support of the Director of National Intelligence.

4.2 RECOMMENDATIONS

The concept of a community S&T organization can be traced back to 1999, when a report by the President's Foreign Intelligence Advisory Board on the total inadequacy of IC S&T—both the development of technical systems and the analysis of technical intelligence—prompted a presidential directive to correct this deficiency. The directive led the IC to create the position of Chief Technology Officer and to provide community funds to establish what is now the Intelligence Technology Innovation Center (ITIC). The IC also initiated another community program, the Advanced Research and Development Activity, which has evolved into the Disruptive Technology Office (DTO). Both of these programs have enjoyed some measure of success, but progress has been evolutionary at best. The rate of change in the threat and the growth of worldwide competition in S&T clearly indicate the need for a greater, more unified effort.

4.2.1 iARPA

In a recent series of addresses the Director of National Intelligence (DNI) announced plans to form an R&D program for the IC that draws upon lessons learned from the Defense Advanced Research Projects Agency (DARPA). The proposed iARPA would model itself on those characteristics of DARPA that apply to the IC.

This concept is not new. In 1999, the ISB's predecessor organization, the Advanced Technology Panel (ATP), published a paper by Danny Hillis and Lionel Olmer that discussed such an initiative. The paper was written at the request of the Director of Central Intelligence in response to a Congressionally Directed Action that raised the issue of an IC research organization along the lines of DARPA—that is, an iARPA. While supporting the concept, the ATP noted: "Crucial for an IARPA would be (a) enough money to do something good, (b) enough time to show success, (c) organizational independence, and (d) a strong director with technical stature." More recently, in a speech presented at the Woodrow Wilson International Center for Scholars in September 2006, the DNI noted that the National Academy of Sciences had proposed an emulation of DARPA for the Department of Energy, to be known as ARPA-E. The

National Academy recommendation stated that "ARPA-E would have a very small staff, perform no research itself, would turn over its staff every 3–4 years, and would have the same personnel and contracting freedoms now granted to DARPA."[66] The Academy also suggested that ARPA-E be an independent organization with its own office space and be led by a respected technical professional.

During a recent ISB quarterly meeting centered on organizational issues for enterprise-level R&D organizations Dr. Frank Fernandez, former director of DARPA, commented on the unsuccessful attempt by the Department of Homeland Security to replicate DARPA. He noted that HS-ARPA, as it was called, could not hire staff, had no office space, and ran programs that lasted no longer than six months. By contrast, he identified three factors critical to the success of DARPA: the right staff and leaders, adequate resources, and top-level support, meaning Congressional backing.

We enthusiastically endorse the iARPA concept, but urge the DNI to establish the program in a manner that maximizes the probability of success. The effort has strong support across the community, but only if it is carried out correctly. The right to fail, professional technical management, and adequate resources of both staff and money allowed DARPA to succeed. These same elements, combined with the *time* to try and try again, are the key ingredients of successful human intelligence (HUMINT). Unless they are also key elements of an S&T effort that will enable the new HUMINT that the IC now so desperately needs, iARPA cannot succeed. **More specifically, if iARPA simply combines existing programs, all of which lack adequate staffing and finances, it will maximize the probability of failure, not success. That legacy would have agonizing consequences.**

As the National Academy suggested for ARPA-E, we recommend that the iARPA program have a rotational staff, and that half of this staff come from the private scientific community and half from the IC. Staff assignments should last no less two years or more than four years. This constant infusion of new talent and new ideas would yield obvious benefits to the IC. Scientists on rotation to iARPA would learn what intelligence needs, and would remain valuable resources for the IC when they return to their home assignments. Just as critical, intelligence analysts on rotation to iARPA would gain a better understanding and

[66] *Id.*

appreciation for the basic areas of S&T in which they must assess progress by other countries and the potential damage or disruption to our national security.

Like DARPA, **iARPA should be a multilevel security program that enables the use of modern IT tools.** Current security restrictions and the lack of up-to-date equipment prevent many IC professionals from performing their tasks as quickly or as effectively as they might otherwise.

Finally, and just as critical, **we urge the DNI to exercise his reallocation authorities and ensure that iARPA is funded at a minimum of double the level of the existing organizations (ITIC and DTO) that are being transferred into this new program.** This would make discretionary funding available for new ideas and for longer term programs,[67] and avert poaching on programs already underway. Without this level of funding, without the expectation that failures will outnumber successes, and without an integrated mix of talented personnel from within and outside the IC who are experienced across collection and analysis, the new enterprise will simply replicate what already exists: do what we have always done, get what we have always gotten, achieve what we have always achieved.

4.2.2 Remove Artificial Boundaries

The current model, in which collection, S&T, and analysis are separate functions bounded and enforced by separate organizations, is wrong for today's problem set. Many within the IC recognize its shortcomings and are working at their own levels to address them. Yet the DNI's own organization, with separate directorates for S&T, Collection, and Analysis, lends support to those who resist changing this Cold War holdover. Once again, the DNI should endorse by words and action the need for a more efficient system.[68]

We recommend that the DNI lead the effort to change the old organizational philosophy by restructuring the Office of the DNI to reflect a multidisciplinary approach. Numerous examples of ways to

[67] Recall that in the CORONA program launch after launch—eleven in all by May 1, 1960, eight of which carried cameras—resulted in failure. The only variation was in the cause.

[68] Toyota learned this production approach in the late 1990s and now thrives as the once-dominant U.S. auto industry giants are in junk bond status. See James P. Womack, Daniel T. Jones, and Daniel Roos, *The Machine That Changed the World: The Story of Lean Production* (New York: Harper Collins, 1991).

achieve this have emerged from all levels of the community. We cannot cite the one best—or even good enough—method or identify what it would involve. We do, however, recommend that the IC initiate a number of "experiments" that will help lead the way and at the same time address key problem areas without causing serious disruption to the current organization. We assume that leaders within the DNI's three organizations already have significant interaction. The goal would be to reflect that interaction in an organizational structure that would allow all IC professionals to share in this kind of collaborative working environment among and between the current stovepipes.

4.2.3 Tap New Resources Resulting from Globalization

We recommend that the DNI encourage the IC to recognize and take advantage of the resources that globalization offers. More U.S. citizens than at any previous time in history hold various positions in foreign and foreign-owned companies all over the world. Yet the IC still uses the collection approaches that were developed in decades past. Because these approaches rely strictly on trained intelligence professionals they are relatively safe (pose lower risk). However, they provide nowhere near the potential payoff that would allow IC professionals to gain better understanding not only of specific issues but also of the culture, interests, and intent of those whom we claim to understand in our formal assessments. Nothing can replace direct interaction (even virtual interaction across the Internet and collaboration sites) between these resources and the IC professional who must prepare the assessments.

Similarly, we now have an unprecedented number of foreign students studying in our premier graduate schools, U.S. students studying abroad, and even foreign-born, naturalized U.S. citizens at work in high-tech companies both in the United States and overseas. The information they possess and their impressions of what S&T disciplines and developments are important to other nations, and what progress those nations are making, can prove critical to the IC. We recognize the possibility that such people may have divided loyalties, but the combined expertise of collectors, analysts, and S&T subject experts should enable the IC to identify reliable and knowledgeable sources. Again, direct interaction would prove essential, as opposed to the use of intermediaries who collect data and then finalize a report.

We offer the following recommendations to help the IC take advantage of the new resources provided by globalization.

1. **Allow IC professionals to participate directly in worldwide collaboration programs of interest.** Taking this one step further, the DNI should sponsor such collaborative efforts.

2. **Allow IC professionals direct access to knowledgeable people involved in foreign or foreign-owned companies of interest,** even if these people have no formal connection to the IC. By working in teams that combine expertise in collection, analysis, and S&T the IC professionals who make these contacts should break down some of the barriers to this type of direct relationship. For example, having an S&T expert from the IC interact with the private sector source would probably elicit more, and more useful, information than relying on a person who lacks specific S&T knowledge.

It is essential that the IC adopt new approaches for interaction and collection against the most important areas of S&T without delay. Only a small, focused effort can ensure that this is done most effectively—that is, in areas where the benefit to our national security interests will be the highest—and in ways that do not jeopardize either ongoing sensitive activities or place our own secrets at risk. We recommend that the DNI direct a group of collectors, analysts, and S&T subject experts to identify several S&T areas especially likely to provide real insights into disruptive technologies, as well as areas where technologies of potential collection advantage to the U.S. IC might be found. On the basis of this information, interaction and investigation by collectors and analysts should identify those target foreign companies and the U.S. individuals on their staff who are most likely to have access to these technologies. With this as a focus, the DNI should oversee a new approach to interaction between IC experts—operators as well as analysts—and these key resources. This approach would allow for a full range of engagement with sources, from traditional agent recruitment by clandestine HUMINT operators to development of more nuanced, but nonetheless critical, relationships by IC analysts and other subject matter experts.

4.2.4 Utilize the Talents of Those Awaiting Results of the Lengthy Clearance Process

We offer the following recommendations to help the IC make better use of its full staff capabilities.

1. **Provide a means to make productive use of people selected for IC employment who are undergoing the seemingly endless security**

investigation process. The IC should put these candidates to work in a multilevel security environment that permits them to contribute immediately, even if not at the level of the desired final clearance, and—most important—allows them to use the state-of-the-art IT tools available to the rest of the world.

2. **Provide a means to employ immediately those foreign-born, naturalized U.S. citizens whose clearance process may easily take years to complete**—with the chance that they will never obtain more than collateral clearances. The IC desperately needs to tap their knowledge of the language and culture of their home countries and of groups of interest. The IC should create the appropriate unclassified or collateral-only environment and again provide them with modern IT tools.

4.2.5 Accept and Encourage Risk Taking

We recognize that much of what we recommend involves change and that, regrettably, pervasive risk aversion hobbles innovation in the IC more severely than ever in the past. The IC must be willing to confront not merely the risk, but the certainty, of different levels of failure inherent in what we suggest. Such failure often implies exposés, headlines, and finger-pointing that can shorten or end careers. This must be balanced against of the loss of life that could result from the current practice of taking little or no risk. The dramatic change in the nature of the threat and the potential adversaries we face compounds this problem to critical levels.

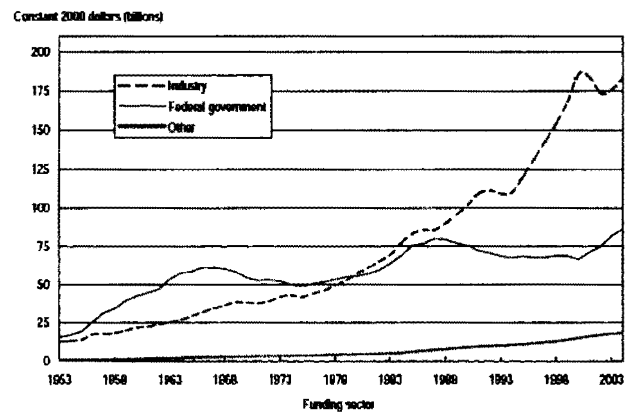
Many organizations, private and government, now use risk assessment methodologies to quantify in some sense the level of risk associated with any actions taken. **We recommend that the DNI sponsor a risk assessment approach that will provide some foundation for judging the risks associated with actions such as those we suggest,** even if only in a relative sense.

We have taken the approach of making our recommendations directly to the DNI. In almost all cases, only personal action by the DNI on those recommendations he approves can create the necessary impetus and organizational support that would allow them to succeed.

APPENDIX A: RESEARCH AND DEVELOPMENT

U.S. research and development (R&D) spending overall grew to $ 319.7 billion in 2005, growing 2.5 percent from 2004. It is projected that the 2006 data will show continued growth to $328.9 billion, largely due to investments by the business sector.[69]

Although spending has continued to increase overall, the sources of funding and type of research conducted have shifted. Beginning in approximately 1979, private industry funding for R&D overtook federal spending (Figure A-1).



FFRDC = federally funded research and development center

NOTE: R&D data for 2004 are projections.

SOURCE: National Science Foundation, Division of Science Resources Statistics. National Patterns of R&D Resources (annual series).

Figure A-1. U.S. R&D Spending by Funding Sector: 1953–2004

The federal share of R&D funding fell to a low of 24.9 percent in 2000. It then rebounded to a projected 29.9 percent as the business sector entered a slowdown and federal spending expanded, particularly in the areas of defense, health, and counterterrorism.[70] In fact, three-quarters of the growth in the government R&D budget between 2001 and 2005 is attributable to defense R&D.[71] However, more recent budget figures

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[69] "2005 R&D Funding Forecast," *R&D Magazine*, January 2005, F3;"2006 R&D Funding Forecast," *R&D Magazine*, January 2006, F3.

[70] National Science Board, *supra*, 4–5.

[71] Organisation for Economic Cooperation and Development, *OECD Science, Technology and Industry Scoreboard 2005*, Executive Summary, http://www.oecd.org/document/43/0,2340,en_2649_33703_35455595_1_1_1_1,00.html

indicate that funding for federal R&D in the FY2006 budget, after adjusting for inflation, would decline for the first time since 1996.[72]

This development has significant implications for advancing R&D. In essence, it has meant that control over the types of research conducted has moved to the private sector. Because federal and industry funds tend to be used for different types of R&D, this shift between business and federal spending has had a significant impact on the allocation of moneys among the types of R&D.

A.1 Basic Research

Most basic research[73] is funded by the federal government and performed at universities and colleges (Figure A-2). Because the payoff for basic research is often long in coming, its results may be unmarketable, and rewards diffused among many users, the private sector is less likely to perform such research (Figure A-3).

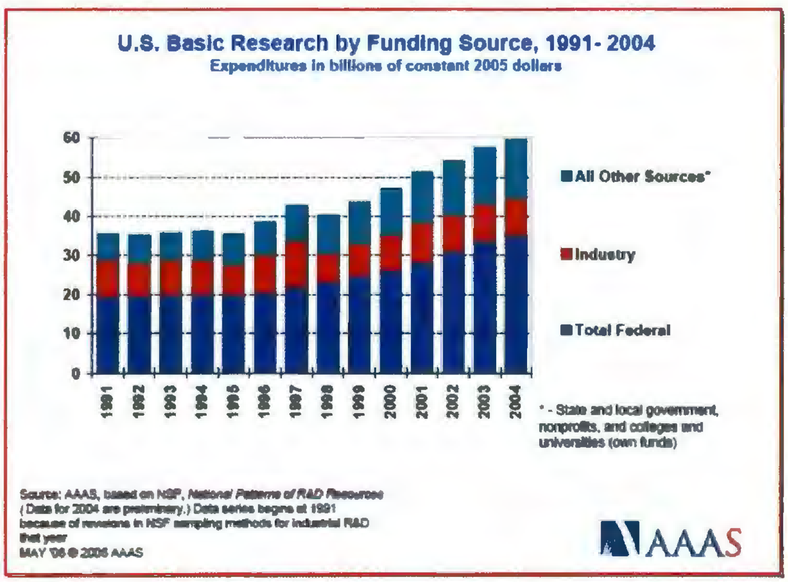
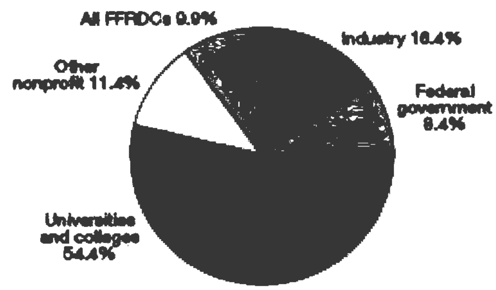


Figure A-2. U.S. Basic Research by Funding Source 1991–2004

[72] CRS, *Science and Technology Policy, supra.*
[73] *Ibid.*, 1.



Basic research, by performing sector

FFRDC = federally funded research and development center

NOTES: Figures rounded to nearest whole number. National R&D expenditures estimated at $313 billion in 2004.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-3, 4-7, 4-11, and 4-15.

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Figure A-3. Basic Research by Performing Sector, 2004

Universities and colleges have benefited most from increased federal spending in the past five years (Figure A-4). Since 1990, inflation-adjusted academic R&D expenditures have almost doubled, driven by federal and institutional funds. These expenditures reached $40 billion in 2003, the second-fastest growth of any U.S. R&D sector. The federal government supplied 62 percent of these funds, up from 59 percent in 1990, reversing the long-declining share of federal dollars. The universities themselves provided an additional 19 percent.

State government and industry support grew slowly: state government funding because of unfavorable budget conditions and industry funding because of retrenchment after the collapse of the dot.com industry. The share of academic research expenditures directed to the life sciences rose to 59 percent, whereas the shares of engineering and the physical sciences declined.

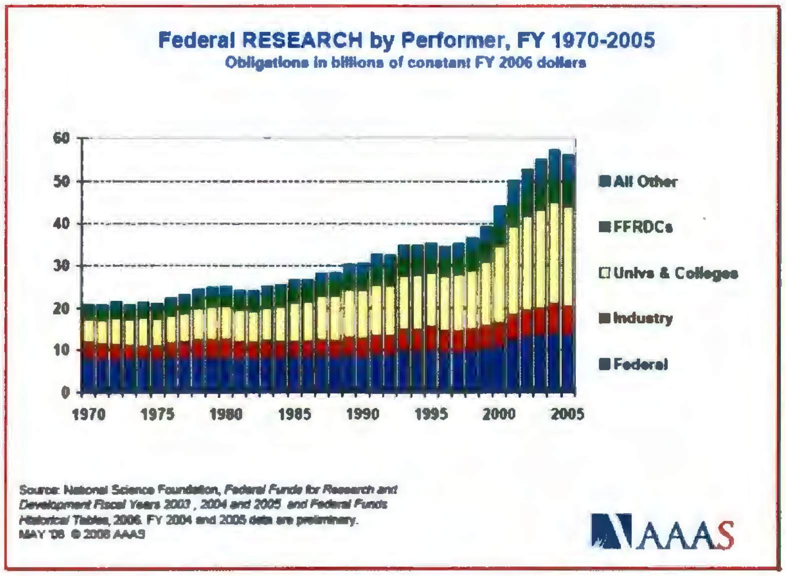

Figure A-4. Federal Research by Performing Organization, FY 1970–2005

Academic institutions have become increasingly reliant on federal funds for conducting their research (Figure A-5). This becomes significant in view of the characteristics of the faculty members who actually conduct the research, many of whom are foreign born.

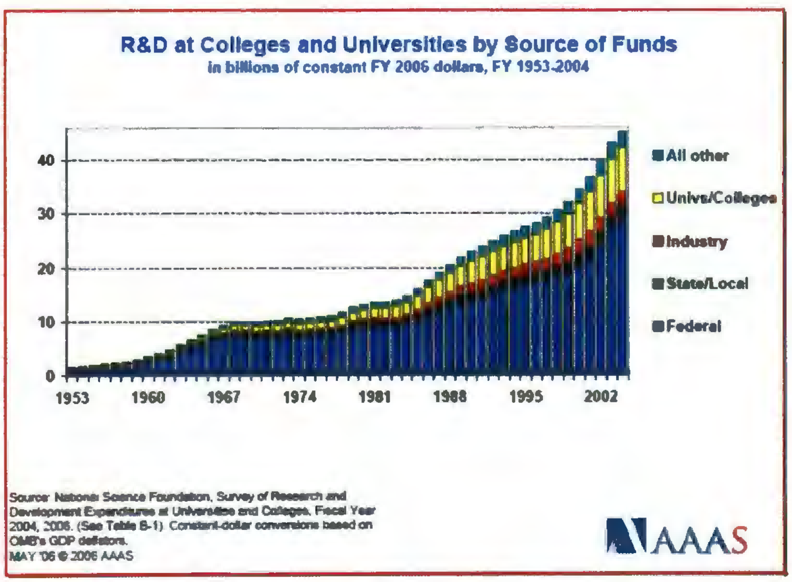

Figure A-5. R&D at Colleges and Universities by Source of Funds

The subject areas of research funded by the federal government have also undergone significant changes in recent years, with the primary increases in recent years occurring in biomedical research conducted by the National Institutes of Health (NIH) (Figure A-6). However, in the FY2006 budget, after the 1 percent rescission, NIH funding in current dollars declined for the first time in 36 years. While total federal research funding was budgeted (pre-rescission) to increase to $135.7 billion, representing a 2.8 percent increase over FY2005 estimated funding levels, most of the growth was attributable to increases in defense weapons systems and the National Aeronautics and Space Administration's human space exploration technology program.[74]

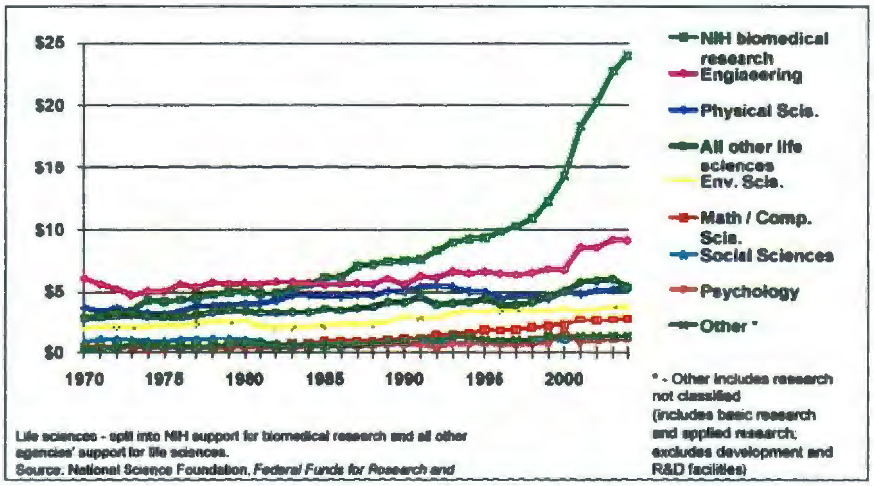

FIGURE 3-13 Trends in Federal Research by Disciplane. FY 1970 -2004
SOURCE: AAAS based on NSF, Federal Funds for Research and Development FY 2002, 2003, 2004. FY 2003 and 2004 data are preliminary. Constant-dollar conversions based on OMB's GDP deflector.

Figure A-6. Trends in Federal Research, by Discipline, FY 1979–2004

As recent events show, however, merely budgeting money for research does not mean that it will be spent. The Department of Homeland Security (DHS) failed to spend $200 million in R&D money from past years, and the funds had to be rescinded. Lawmakers and recently retired Homeland Security officials have raised concerns that DHS's R&D effort is hampered by bureaucracy, lack of strategic planning, and failure to use money wisely.[75]

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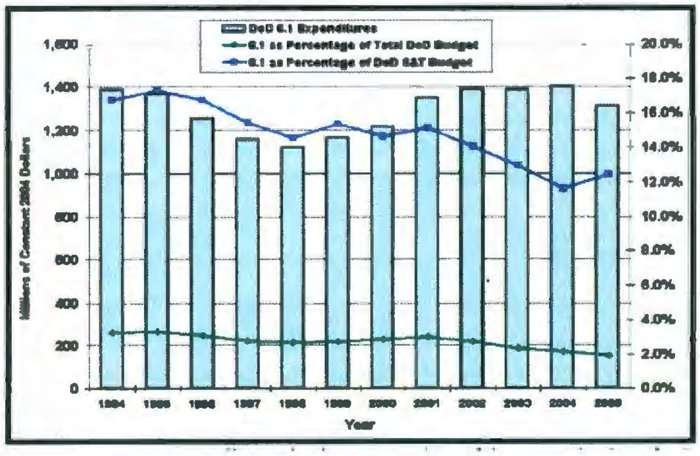
[74] *Ibid.*, 2.
[75] Associated Press, "Bush Sought to Cut $6 Million in Screening Technology," August 13, 2006.

Basic research has also declined as a proportion of federal funding. This is evident, for example, in the Department of Defense (DoD) budget, although the latest year's figures show some rebounding (Figure A-7).



Source: National Science Board S&E Indicators, 2004. Arlington, VA: National Science Foundation, 2004.

Figure A-7. Expenditures in the 6.1 Portion of the DoD Budget

A.2 DEVELOPMENT R&D

Purely development activities that are directed toward the creation of new goods, services, and processes are primarily funded by industry and constitute the majority of industry R&D spending (Figure A-8). Thus, as support for U.S. R&D has shifted from federal funds to industry funds, the amount of money spent on long-term basic research using industry funds has remained relatively flat, while spending on short-term developmental projects has increased substantially.

In 2003, over one-third of all industry-funded R&D was concentrated in the computer and electronic products industry and computer-related service companies.[76] Former secretary of defense William Perry told the United States-China Economic and Security Review Commission ("China Commission") that

> ...basic research, "i.e., research aimed at developing new technologies rather than developing new applications for existing technologies, is critical to generating future technological advances, but that nearly all R&D

[76] National Science Board, *supra*, 4–5.

currently undertaken by U.S. industry is focused on less risky product development involving existing technologies."[77]

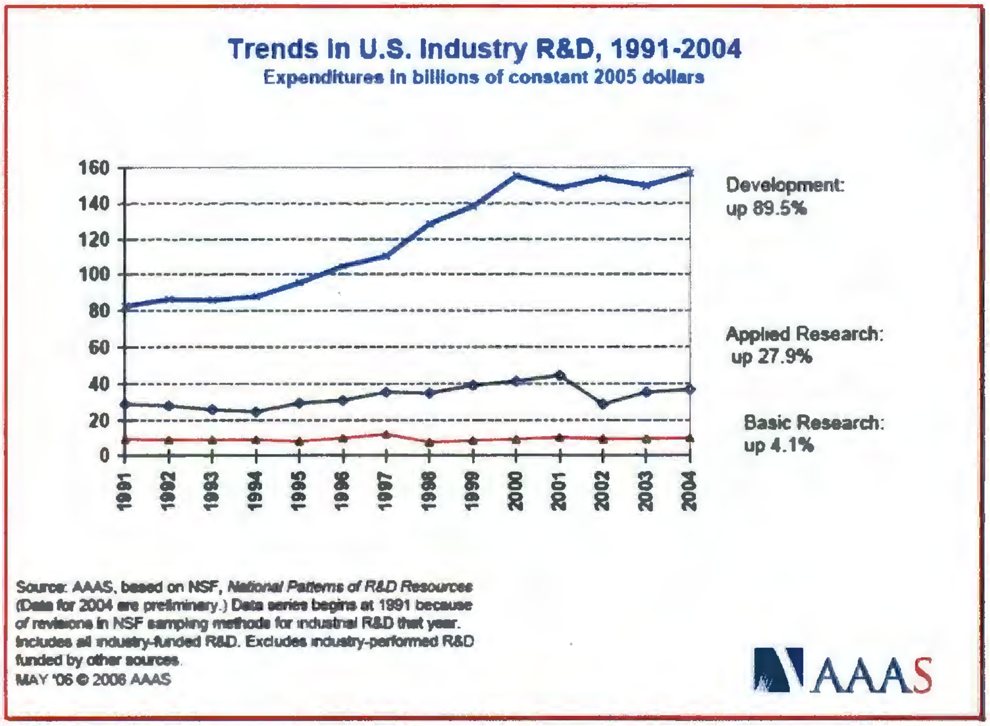


Figure A-8. Trends in U.S. Industry R&D, 1991–2004

A.3 The Shifting International Landscape

The rest of the world has not remained idle while the U.S. landscape has changed. Indeed, the National Academy of Sciences Committee on Prospering in the Global Economy of the 21st Century stated in their report that "having reviewed the trends in the United States and abroad, the committee is deeply concerned that the scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength."[78] Others have suggested that the problem is not so much that the United States is in decline but rather that others

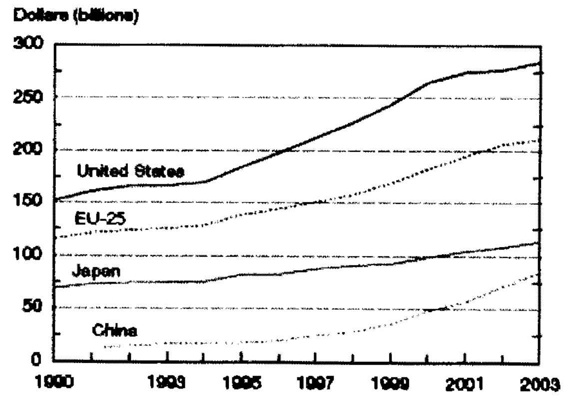
> ...are advancing quickly from behind, putting all their economic resources into moving their countries forward. The problem is that even if the United States were doing everything right, the world still poses an unprecedented

[77] China Commission, 95.
[78] *Gathering Storm*, 2.

competitive challenge. Unfortunately we are not doing everything right, and this compounds the challenges that we face.[79]

Foreign investment in R&D has been growing at a greater pace than U.S. R&D. Statistics for Organisation for Economic Cooperation and Development (OECD) and nonmember economies show that (underestimated) worldwide R&D expenditures, unadjusted for inflation, rose from $377 billion in 1990 to $810 billion in 2003, the last year for which data were available (Figures A-9 and A-10). The OECD countries' share dropped from an estimated 93 percent to 84 percent of the total over the period; the calculation is based on the reported R&D expenditures of eight non-OECD members whose 1995–2003 average annual growth rate of 17.1 percent contrasted sharply with the 5.6 percent annual growth for OECD members.

Figure O-6
R&D expenditures of selected region and countries: 1990–2003



EU = European Union

NOTES: All data calculated by Organisation for Economic Co-operation and Development (OECD) with purchasing power parities. Data differ somewhat from U.S. dollar figures. EU-25 is EU-15 plus 10 new member states.

SOURCE: OECD, *Main Science and Technology Indicators* (various years).

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Figure A-9. R&D Expenditures of Selected Regions and Countries, 1990–2003

[79] China Commission, *supra*, citing testimony of William Archey, 94.

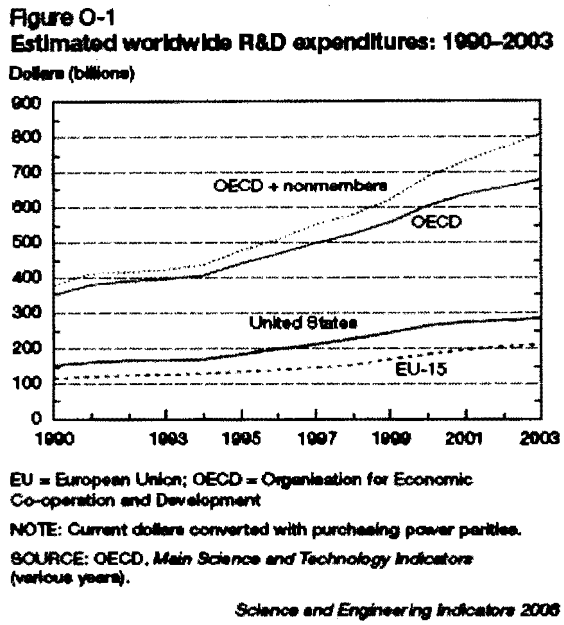

Figure A-10. Estimated Worldwide R&D Expenditures, 1990–2003

Industry is also increasingly looking beyond national borders as it decides where to locate R&D activities. The United States remains an attractive venue for foreign companies seeking to conduct R&D. From 1990 to 2002, R&D expenditures in the United States by majority-owned affiliates of foreign-based multinationals rose from 8 percent to 14 percent of total U.S. industrial R&D performance. R&D expenditures by U.S.-owned companies abroad rose from about $12 billion in 1994 to $21 billion in 2002. Foreign sources supported more than a quarter of the United Kingdom's industrial R&D in 2002, while Canada's foreign support rose to 21 percent and that of the 15 European Union members (EU-15) rose to 10 percent, including within-EU funds flows. Notably, foreign-owned companies and foreign-born inventors now account for nearly half of U.S. patents.[80]

The global nature of S&T markets is also reflected in the rising number of corporate international alliances devoted to joint R&D or technology development. Industrial innovation increasingly involves external partners to complement internal capabilities, share costs, spread market risk, expedite projects, and increase sensitivities to geographic

[80] National Summit on Competitiveness, *supra*, 1.

variations in product markets. The number of new international alliances rose from under 100 in 1980 to 183 in 1990 and 342 early in the new century. Historically, U.S. companies have been involved in 75 percent to 86 percent of these alliances. These multinational corporations and organizations compete against or even overshadow national entities and interests, which can result in the blurring of distinctions between government and commercial goals.[81] Moreover, existing mechanisms to identify foreign membership, control, or influence over U.S. firms whose work is vital to U.S. defense and intelligence systems have proven inadequate to keep up with the rapid changes in ownership, control, and influence.[82]

R&D spending by U.S.-based multinationals is increasing in Asia. Although Europe remains the single largest location of these R&D expenditures, accounting for just over 60 percent of the total, its share has slipped by about 10 percentage points since 1994. Over this period, the combined share of Europe, Canada, and Japan declined from 90 percent to 80 percent of the total. The share of other Asian economies rose from 5 percent in 1999 to 12 percent as R&D expenditures by U.S.-based multinationals more than doubled to about $3.5 billion in the region, compared with $1.5 billion during the 1994–1998 period. This increase was fueled primarily by steep investment growth in China (more than $1 billion in 2002 and rising) and the Asia-8 economies. U.S. R&D expenditures in Japan increased only moderately.[83] By 1999 it was reported that 200 of *Fortune* magazine's top 500 companies had already invested in China.[84]

According to data compiled by OECD, China's spending on R&D reached $84.6 billion in 2003, up from $12.4 billion in 1991. Although the precise international comparability of the data remains questionable, this would put China in third place, behind only the United States and Japan and ahead of Germany. Average annual increases in R&D investment over the 12-year period ranged from 4 percent to 5 percent for the United States, EU-25, and Japan. These contrasted sharply with the 17 percent average annual growth for China, which is accelerating: for the past five years, China's R&D expenditures have registered 24 percent average annual increases. Over the same period, the ratio of China's R&D to its

[81] Counterintelligence in a Time of Rapid Change: The Impact of Technology and Globalization, June 26, 2006.
[82] GAO, *supra*.
[83] National Science Board, *supra*.
[84] *People's Daily*

gross domestic product—indicative of the relative prominence of R&D in China's rapidly growing economy—rose from 0.6 percent to 1.3 percent, compared to about 1.8 percent for the EU-15 and 2.6 percent for the United States. China's R&D expenditures are rapidly approaching those of Japan. OECD data (Figure A-11) show China's investment at 17 percent of Japan's in 1991 but at 74 percent of Japan's in 2003. Relative to the EU-25, the comparable Chinese figures were 10 percent and 40 percent, and relative to the United States the increase was from 8 percent to 30 percent. Even if more fully comparable Chinese figures reduced the growth statistics somewhat, such a rapid advance in comparison to the leading R&D-performing countries and regions would still be unprecedented in recent history.

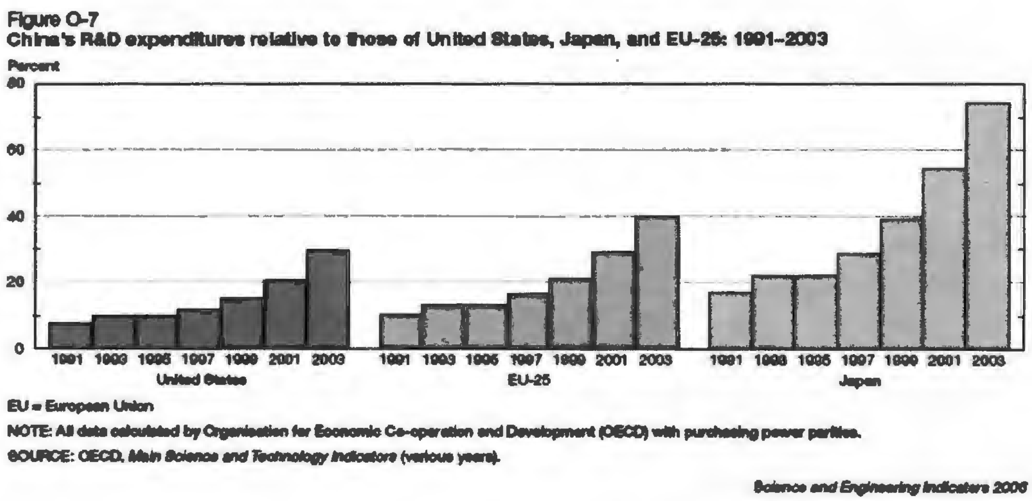

Figure A-11. China's R&D Expenditures Relative to Other Nations, 1991–2003

The increase in spending is reinforced by the growth in China's industrial research workforce, which expanded from 16 percent of the size of its U.S. counterpart in 1991 to 42 percent in little more than a decade.[85] By 2003 the ratio reached 66 percent, with 862,000 researchers in China compared to 1.3 million in the United States. This outstripped both Japan, which had 675,000, and the Russian federation, which had 487,000.[86]

The China Commission found that:

[85] National Science Board, *supra*, 4–6.
[86] OECD, *supra*.

> Science and technology (S&T) development is the centerpiece of China's comprehensive strategy to build national power. As a result, the Chinese government has a comprehensive, coordinated strategy for S&T development, which it began to implement in the mid 1980s with the 863 program. This strategy translates into government policies to encourage growth and investment in key industries, among which are software and integrated circuit industries. Such policies include foreign investment incentives, tax incentives, government subsidies, technology standards, industrial regulations, and incentives for talented Chinese students studying and working overseas to return to China. Many of these policies make it difficult, if not impossible, to achieve a level playing field in this area of U.S.-China trade and jeopardize long-term U.S. leadership in this vital sphere.[87]

The Commission noted further that, "Attracting U.S. and other investment into China has been an important component of this strategy, particularly where transfers of technology and know-how have accompanied this investment."[88]

New industrial technology alliances worldwide reached an all-time peak in 2003 with 695 alliances, according to the Cooperative Agreements and Technology Indicators database. Alliances involving at least one U.S.-owned company have represented the largest share of alliances in most years since 1980, followed by alliances between U.S. and European companies.[89]

In addition, many high-tech companies have begun to locate major research installations outside the United States (Figure A-12). A 2004 survey by *The Economist* reported that the top five countries where companies intend to increase their R&D efforts outside their home country were China, the United States, India, the United Kingdom, and Germany. Most notable is the dramatic increase in foreign investment in China. In 1997 China had registered fewer than 50 multinational corporation research centers. By mid-2004, a mere seven years later, the Chinese government had registered over 600 such facilities, many belonging to large, U.S.-based multinationals.[90] Another reliable report said this figure had actually topped 700.[91] In 2003 China cited a *Fortune*

[87] China Commission, *supra*, 86.
[88] *Ibid.*, 85.
[89] National Science Board, *supra*, 4–6.
[90] Freeman, *supra*.
[91] China Commission, *supra*, 88.

survey showing that over 92 percent of multinational corporations will consider setting up regional headquarters in China in the future.[92]

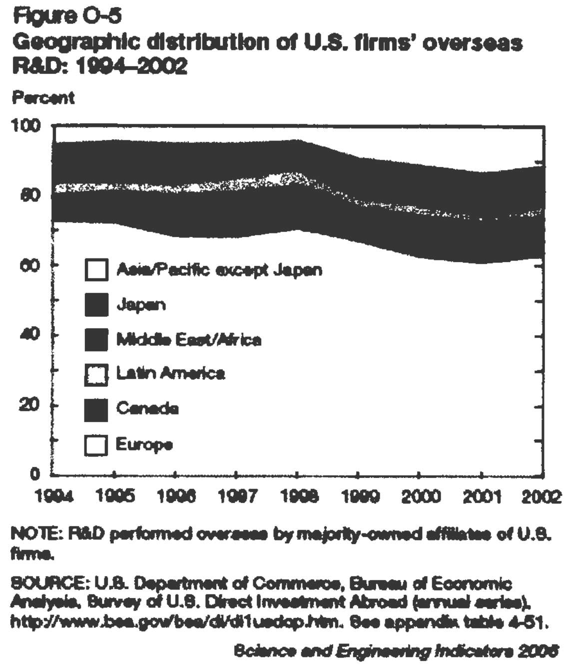

Figure A-12. Geographic Distribution of U.S. Firms' Overseas R&D, 1994–2002

Over the last decade, the share of R&D sites based in the United States has fallen from 59 to 52 percent. At the same time the number of sites based in Western Europe has dropped from 24 to 22 percent, while sites based in China grew from 4 to 11 percent and those based in India grew from 4 to 7 percent of sites worldwide. Combined, China and India are about to overtake Western Europe as the most important locations where U.S. companies conduct foreign R&D.

In the late 1980s the total share of sites based in countries foreign to the company's home country passed the 50 percent mark and in 2004 stood at 66 percent. Data about plans over the next three years for current R&D networks of surveyed companies reveal that almost all of the planned growth in foreign R&D will be in China and India. The growth will occur primarily in staff numbers as opposed to totally new

[92] Au.china-embassy.org/eng/jmhz/t46221.htm

sites. By the end of 2007 China and India will account for 31 percent of global R&D staff, up from 19 percent in 2004.[93]

Mere growth in sites does not tell the whole story, however. Examination of the adjustment in "R&D footprint" revealed that different factors caused growth in different areas. In China, a low-cost skill base is coupled with companies' need for market and customer access. This suggests that companies are focusing less on large innovation gains in China than in India or Eastern Europe, where other factors dominated. Overall, foreign sites were found to be more likely "to focus on specific areas of expertise within the development process." They also were much more likely to focus on customizing products for local markets. Indeed, the primary reason that companies cited for opening or increasing the size of new sites in China was to be closer to their customers. [94]

The China Commission found that the sophistication of the technology developed and produced by China is increasing at an unexpectedly rapid pace.

> China has been able to leapfrog in its technology development using technology and know-how obtained from foreign enterprises in ways other developing nations have not been able to replicate. This rapid advancement is evident in the level of technologies that make up China's fast-growing trade surplus with the United States in Advanced Technology Products, which increased by 72 percent from 2003 to reach $36 billion in 2004."[95]

The Commission found that China's approach to this development includes "aggressive use of industrial espionage."[96] It also noted that China is making significant progress in developing indigenous firms that have global brand recognition, reputations for producing quality products, and leading-edge R&D programs. China's growth strategy also involves developing different technology standards, which may act as a significant market access barrier to products made outside China.[97]

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[93] Booz Allen Hamilton and INSEAD, "Innovation: Is Global the Way Forward?," 2006, 3–4, http://www.boozallen.com/media/file/Innovation_Is_Global_The_Way_Forward_v2.pdf
[94] *Ibid.* at 6, 9.
[95] China Commission, *supra*, 86.
[96] *Ibid.*, 87. The Commission noted that as a result U.S. companies are taking some precautions with respect to their China operations. For example, it said Intel has not built a fabrication plant in China because it feared that it would lead to a transfer of proprietary information on its chip designs and also on the design and management of its manufacturing process. *Id.* (citing Fred Vogelstein, "How Intel Got Inside," *Fortune*, October 4, 2004, 127).
[97] China Commission, *supra*, 90.

As another commentator stated, Chinese leaders view science and technology as "a kind of warfare." China's progress "on the technology front" is seen as intimately connected to the global strategic balance.[98]

Assessing the actual level of technological development in China is difficult and subject to dispute. The China Commission noted that neither current National Intelligence Estimates on China nor the DoD's annual report to Congress on China's military power contain an assessment of China's technological development.[99] The National Science Foundation (NSF) measures such development through various indicators such as the number of patents granted, the amount of funds U.S. parent companies invest in R&D affiliates in China, domestic gross expenditures for R&D, the number of science and engineering degrees issued, and the percentage of high-tech exports. Using these factors, NSF concludes that, with the exception of the science and engineering degrees indicator, China's technological development is low relative to that of Malaysia, Taiwan, and South Korea. However, the rate of growth for these indicators in recent years is prompting the NSF to update its data on China.

By contrast, others have noted that U.S. government assessments of China have traditionally been based on a belief that China's development lags far behind that of the United States. While China has made "high-level breakthroughs" in nanotechnology, computer chip and semiconductor design, satellites, and supercomputing, "the U.S. government does not currently produce an assessment of the implications of these advancements for China's technological development as a whole or their application specifically to China's military advancement." Researchers from The RAND Corporation and the Atlantic Council of the United States also argued that the NSF indicators do not capture the breadth and depth of China's technological development. Michael Pillsbury pointed out that the Korean government's assessment of China's technological development places it only 2.1 years behind Korea and 7.0 years behind the United States.[100]

Academic R&D has seen robust growth in many countries, as governments try to stimulate basic research capability and to connect universities with industry for the efficient exploitation of research results (Figure A-13). The United States and the EU-25 (including 10 new

[98] Evan Feigenbaum, *China's Technowarriors* (Stanford University Press 2003), 1.
[99] China Commission, *supra*, 96.
[100] *Id.*, citing Michael Pillsbury's Commission-sponsored research and RAND report.

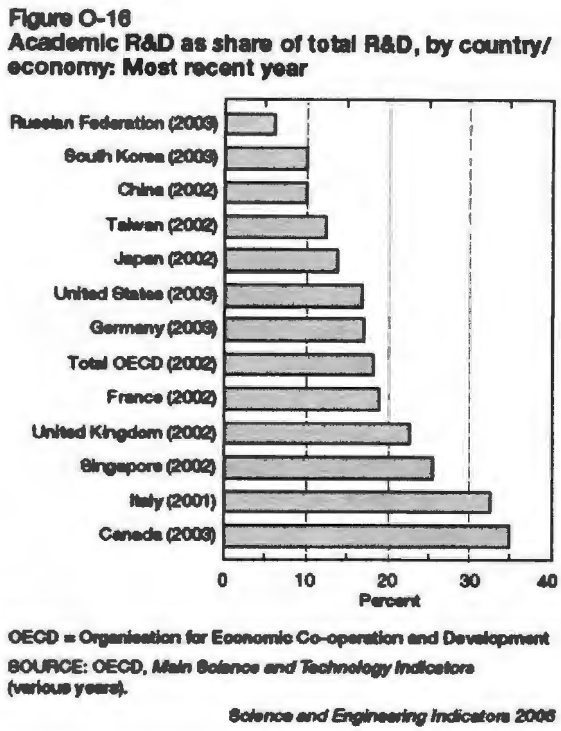


Figure A-13. Academic R&D as a Share of Total R&D, by Country/Economy

member countries) have been spending similar amounts for academic R&D, $41 to $44 billion in 2003, about double their expenditures in 1990. OECD nations other than the United States spent $74 billion, an increase of 120 percent over 1990.

Spending on academic R&D remains less prominent in Asia. China has experienced the most rapid growth in its spending for academic R&D, from $1.1 billion in 1991 to $7.3 billion in 2002, with double-digit growth rates since 1999. Nevertheless, the academic sector, where basic research is conducted in many countries, plays a relatively small role (about 10 percent) in China's R&D system. This is also the case in some other Asian countries, where R&D tends to focus more on applied research and especially on development. In other major OECD nations, the share of academic R&D was at least 14 percent.

Appendix B: The Education of Scientists and Engineers Is Moving Eastward

Like the industrial sector, the education sector is becoming increasingly globalized. Over the past three decades the number of students leaving home each year to study abroad has grown at an annual rate of 3.9 percent, from 800,000 in 1975 to 2.5 million in 2004. Today foreign students earn 30 percent of the doctoral degrees awarded in the United States and 38 percent of those in the United Kingdom. In the United States, 20 percent of newly hired professors in science and engineering (S&E) are foreign born. In China, the vast majority of newly hired faculty at the top research universities received their graduate education abroad.[101]

International degree production is rising and is focused on S&E. The number of first university degrees awarded around the world is rising rapidly, from about 6.4 million in 1997 to 8.7 million in 2002. Particularly strong increases occurred in Asia and Europe, with large numbers and strong gains in engineering and the natural sciences. In 2002, the number of engineering degrees awarded in Asia was more than four times the number of those awarded in North America, and the number of natural science degrees was nearly double. Europe graduated three times as many engineers as North America in 2002 (Figure B-1).

The share of S&E degrees among first university degrees in the United States is lower than in other countries, as is the share of U.S. degrees in natural sciences and engineering (NS&E) – S&E degrees not including the social sciences and psychology. Just under one-third of all first U.S. degrees are awarded in S&E. This statistic has held fairly steady over the years, as has the 19 percent share of NS&E degrees.[102]

[101] Richard Levin, "Universities Branch Out: From Their Student Bodies to Their Research Practices, Universities Are Becoming More Global," *Newsweek*, August 21, 2006, issue.
[102] National Science Board, *supra*, O-12.

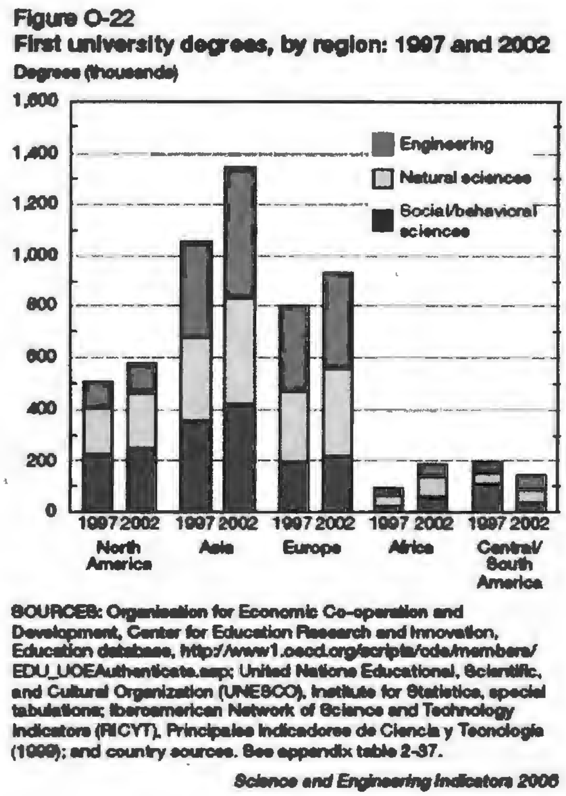
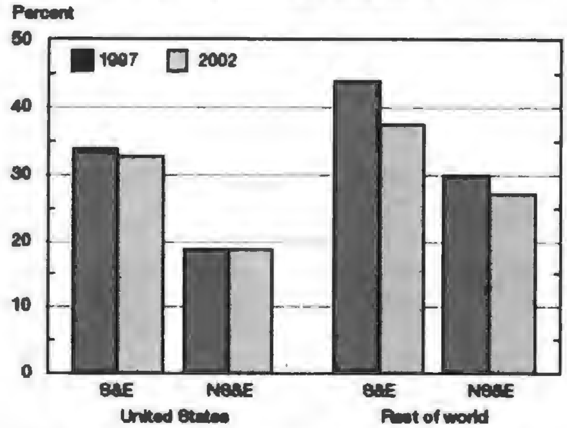


Figure B-1. First University Degrees, by Region: 1997 and 2002

When considering all levels of degrees, however, world trends seem to be moving in the same direction (Figure B-2). In 1997, an average of 44 percent of all degrees awarded in other countries were in S&E. That number fell to 38 percent in 2002. Similarly, the share of NS&E degrees in countries other than the United States declined from 30 percent to 27 percent. This indicates that the worldwide expansion of higher education degrees was stronger in the non-S&E fields than in S&E. In light of these statistics, OECD ministers have expressed concern that young people lack interest in S&E.[103]

[103] *Id.*

Figure O-23
First university degrees in NS&E as share of total first university degrees: 1997 and 2002



NS&E = natural sciences and engineering

SOURCES: China—National Research Center for Science and Technology for Development, unpublished tabulations; Japan—Government of Japan, Ministry of Education, Culture and Science, Monbusho Survey of Education (annual series, 2005); South Korea—Organisation for Economic Co-operation and Development, Center for Education Research and Innovation, Education database, http://www1.oecd.org/scripts/cde/members/EDU_UOEAuthenticate.asp; Taiwan—Ministry of Education, Educational Statistics of the Republic of China (annual series, 2004); Germany—Federal Statistical Office, Prüfungen an Hochschulen 2003 (annual series, 2004); United Kingdom—Higher Education Statistics Agency, special tabulations (2005); and United States—U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System, Completions Survey; and National Science Foundation, Division of Science Resources Statistics, WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 2-38.

Science and Engineering Indicators 2006

Figure B-2. First University Degrees in S&E as Share of Total, 1997–2002

The education of young people in NS&E has become increasingly important for many governments as they try to build more knowledge-intensive economies. Regardless of the percentages of degrees in S&E, as is clear from Figure B-2, Europe and Asia have made great strides in increasing the number of NS&E degrees awarded. Although the percentage of college age students obtaining first university degrees in NS&E vary significantly, from about 16 per 100 24-year-olds in Taiwan to 12–13 in Australia and South Korea and 10 in the United Kingdom. The United States, with just under 6 per 100, ranks 32nd out of the 90 countries for which such data are available. China and India have low ratios (1.6 and 1.0, respectively), due to low overall rates of access to higher education in those countries. But China is strongly trending upward as S&E degree production in China doubled and engineering degrees tripled over the past two decades.104

The number of S&E doctorates internationally has also increased (Figure B-3). In recent years most S&E doctorates (78 percent in 2002) were granted outside the United States. Approximately one-third of the new S&E doctorate holders and one-third of those with doctorates in the natural sciences graduated from EU institutions. At least another third of the engineering doctorates were awarded in Asia, where numbers are likely understated because of incomplete reporting. In 2002 the United States produced only 15 percent of the world's engineering doctorates in 2002. Even then students on temporary visas earned more than half of these degrees.[105]

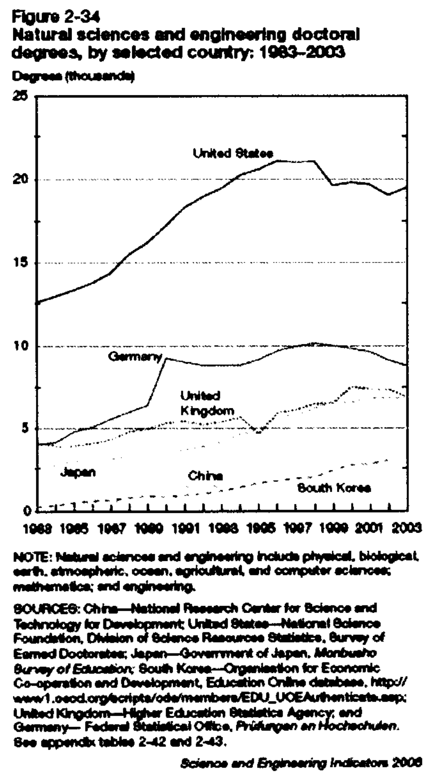


Figure B-3. NS&E Doctoral Degrees by Selected Country, 1983–2003

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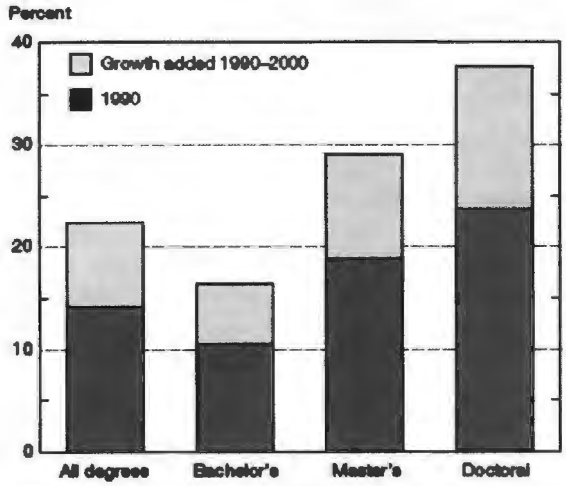
104 *Id.*

105 *Ibid.*, O-12, 13.

The 1990s also showed strong increases in the number of foreign-born individuals holding U.S. S&E jobs. By 2000, this share had increased from 14 percent to 22 percent (Figure B-4). The largest increases were for doctorate holders, from 24 percent to 38 percent. More than half of the engineers in such jobs who held doctorates and 45 percent of the workers in the physical sciences, computer sciences, and life sciences who held doctorates were foreign born. One-third of the foreign-born scientists and engineers working in the United States came from India, China, and the Philippines; China and India alone comprised one-third of the total of foreign-born doctorate holders working here.[106]

Figure O-29
Share of foreign-born scientists and engineers in U.S. S&E occupations, by degree level: 1990 and 2000



NOTE: Data exclude postsecondary teachers because of Census occupation coding.

SOURCE: U.S. Census Bureau, 5-Percent Public-Use Microdata Sample, www.census.gov/main/www/pums.html.

Science and Engineering Indicators 2006

Figure B-4. Share of Foreign-Born Scientists and Engineers in U.S. S&E Occupations, 1999–2000

Foreign students earned one-third of U.S. S&E doctorates and 55 percent of engineering doctorates, while S&E doctorates earned by U.S. white males dropped sharply. The production of U.S. S&E doctorates since 1990 rose from 23,800 to a record 28,800 in 1998 before dropping to 26,900 in 2003. The overall number was strongly driven by the number of foreign students. Each year between 6,800 and 8,700 doctorates were

[106] *Ibid.*, O-14.

awarded to students holding temporary visas—in 2003 these students earned one-third of the total number of doctorates, more than half of the engineering doctorates, 44 percent of the mathematics and computer science doctorates, and 35 percent of the physical sciences doctorates.[107]

Despite some post-September 11 impact on foreign students obtaining visas, many foreign students continue to pursue advanced study in S&E fields at U.S. universities. Moreover, many of these then elect to stay in the United States to work or continue their studies after they complete their initial degree programs. Each year since the mid-1990s between 6,500 and 7,000 foreign students who earned a U.S. S&E doctorate—approximately two-thirds of the total—planned to stay in the United States after receiving their degree. Many of these students remained in the country for years after graduation: 53 percent of the 1993 foreign students who received doctorates were working in the United States in 1997 and 61 percent of the 1998 cohort were still in the country in 2003. However, increasing international competition for these students raises questions about whether these historic patterns will continue.[108]

Of particular note, the Asian nations that have been the source of two-thirds of foreign doctoral candidates in the United States are now developing their own S&T infrastructures that require these highly trained individuals to run them. About 20 percent of foreign doctoral candidates in the United States came from China and 10 percent–11 percent each from Taiwan, India, and South Korea. As these same Asian nations invest heavily in the development of knowledge-based economies and higher education systems they are starting to attract large numbers of foreign-trained Asian scientists and engineers. Thus, there is no assurance of a continued influx of students from this region to the United States, especially since other countries are creating immigrant-friendly policies for those with advanced S&E degrees.[109]

Changes in United States visa policies after September 11, 2001, affected the flow of foreign-born scientists and engineers into the United States. The number of high-skill-related visas issued annually to students, exchange visitors, and others grew rapidly during the 1990s but decreased sharply after September 11. Foreign student visas are now

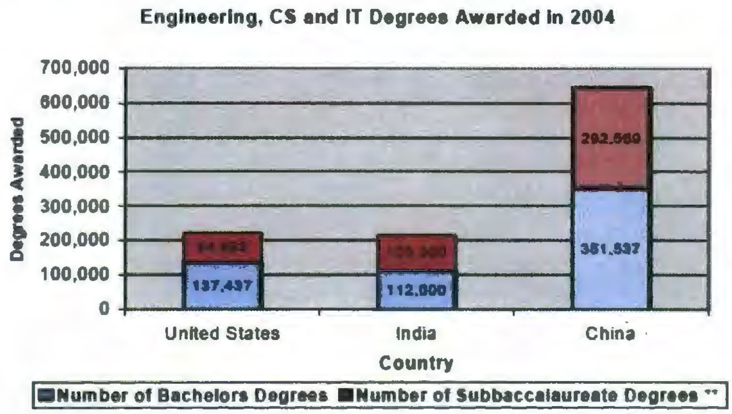
[107] *Ibid.*, O-15, 16.
[108] *Ibid.*, O-16, 17.
[109] *Ibid.*, p. O-16.

recovering but remain down by one-fifth since 2001, while other high-skill visa categories are showing upward trends.[110]

Although these trends and figures may be alarming, some recent studies have looked behind the raw data to provide more context to these figures. A central factor in the studies warning about threats to the technological superiority of the United States has always been the fewer numbers of engineers the United States is graduating compared to China and India (Figure B-5). Figures for 2004 generally report that the United States graduated approximately 70,000 undergraduate engineers in comparison to China's 600,000 and India's 350,000 (Figure B-6). A study at Duke University, however, found that these figures were misleading because the Chinese and Indian figures included three-year training programs and diploma holders as well as four-year degrees.[111] Moreover, in addition to traditional engineering disciplines, these figures include information technology specialists and technicians.[112] Even more incongruous is that, due to definition issues, the Chinese figures "may well include the equivalent of motor mechanics and industrial technicians."[113] When the Duke researchers attempted to "normalize" the data across types of degrees, the data revealed that the differences, although still significant, were not as dramatic as the initial figures. Then, when relative populations were considered, the U.S. figures were comparatively superior to both China and India.

[110] *Ibid.*, p. O-17.
[111] Duke University, Master of Engineering Management Program, "Framing the Engineering Outsourcing Debate: Placing the United States on a Level Playing Field With China and India" (Durham, NC: Duke University School of Engineering, December 2005), 2, http://memp.pratt.duke.edu/downloads/duke_outsourcing_2005.pdf
[112] *Ibid.*, 3.
[113] *Ibid.*, 7.

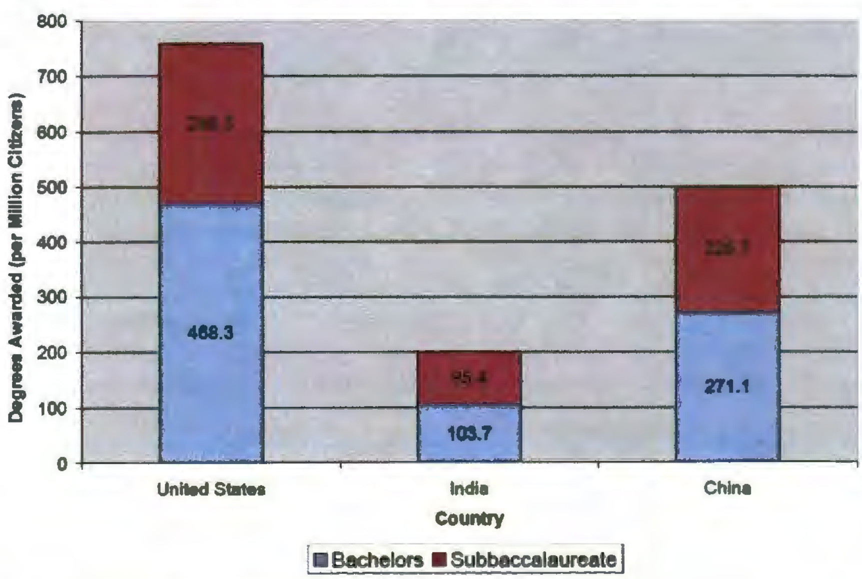
Graph 1: Engineering, Computer Science and Information Technology Degrees Awarded in 2004



Note: Shaded China data may constitute an overestimate.

Figure B-5. Engineering, Computer Science, and Information Technology Degrees, 2004

Graph 2: The Number of Bachelor's and Subbaccalaureate Degrees in Engineering, CS and IT Awarded Annually per Million Citizens



Note. China data may constitute an overestimate

Figure B-6. Bachelor's and Subbaccalaureate Degrees in Engineering, CS, and IT Awarded Annually, per Million Citizens

The Duke study also looked behind the figures to consider the qualitative aspects of the individuals and their education. The study differentiated between "transactional engineers" who are lower paid and do routine work and "dynamic engineers" who possess higher technical skills as well as strong interpersonal skills and the ability to communicate across borders. The study concluded that

> ...the real threat to the United States' science and technology economy exists in a subset of the engineering populations produced by China and India. Foreign dynamic engineers trained by accredited universities with high language proficiencies and close proximity to their country's industrial and commercial centers are the most likely to compete with U.S.-based engineers for offshore engineering jobs, and they also will be central to innovation drives in their domestic economies.[114]

A study conducted by McKinsey & Co. concluded that less than 10 percent of Chinese job candidates overall would be suitable for work in a foreign company. Looking at engineers in particular, the study found that Chinese applicants for engineering jobs suffered because the Chinese educational system teaches theory instead of application. By contrast, engineering graduates in North America or Europe work in teams on practical problems. As a result, McKinsey estimated that China's pool of young engineers "suitable for work in multinationals is just 160,000—no larger than the United Kingdom's."[115]

In addition, the study found that available graduates were so dispersed across universities and colleges as well as cities that as much as half of the total graduate pool is not easily accessible to employers. Less than one-third of the 2003 graduates studied in the top ten university towns. Only one-quarter live in a city or region close to a major international airport—a requirement of most multinational companies. Finally, only one-third move to a different province for work.[116]

McKinsey predicts that China will in fact experience a shortage of suitable labor in the near future. Examining employment demands by large foreign-owned companies and joint ventures that do business in China, McKinsey estimated that these companies will employ almost 70 percent of China's suitable graduates before demand from smaller multinationals or Chinese companies is considered. In fact, in 2003 unemployment rates among China's university graduates was just 1 percent. The study predicted that over the next 10 to 15 years Chinese

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[114] *Ibid.*, 9.

[115] McKinsey Global Institute, "Addressing China's Looming Talent Shortage," October 2005, 5–6, http://www.mckinsey.com/mgi/publications/Chinatalent.asp

[116] *Ibid.*, 7.

companies may need as many as 75,000 leaders who can work effectively in global environments. Today, they have only 3,000 to 5,000 such employees.[117]

Similar trends are evident in India. McKinsey estimated India's supply of young professionals to be 14 million: 1.5 times that of China and almost twice that of the United States. But again multinationals would only hire 10–25 percent of the 2.5 million graduates each year, with approximately 25 percent of engineering graduates falling into in the hirable group. McKinsey attributes this to the great disparity in the quality of Indian universities. Moreover, the best graduates from the top schools often emigrate.[118]

These labor issues that may act as a brake on China's and India's projected runaway growth may be reinforced by problems in their financial systems. Both countries are "pursuing growth strategies based on relatively free markets, yet neither has the financial system it needs to sustain rapid and efficient growth in the years ahead."[119] Notably, both countries' financial systems are distorted by government efforts to achieve social aims. In China, the government is ensuring a continued flow of funding to its many large but highly inefficient state-owned enterprises so as to preserve jobs. Wholly or partially state-owned companies account for 73 percent of bank loans, even though private companies account for over half of China's gross domestic product. A major outcome of these policies is China's large volume of non-performing loans.[120]

In India, government funding is directed toward the large budget deficit and the country's rural investment priorities. Although India's private sector has a number of highly productive companies, the Indian government requires banks to give lending priority to state-owned companies and designated sectors, such as household enterprises and agriculture. As a result, only 43 percent of India's commercial credit goes to private companies, and the financial system is less able to finance growth.[121]

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[117] *Ibid.*, 8–9.
[118] Diana Farrell, "Don't be Afraid of Offshoring," *Business Week*, March 22, 2006.
[119] McKinsey Global Institute, "A Tale of Two Financial Systems: A Comparison of China and India," September 2006, http://mckinsey.com/mgi/publications/talefinsys.asp
[120] *Ibid.*, 6–7.
[121] *Ibid.*, 10–11.

Although none of the above factors is sufficient to eliminate concerns about these countries' increasing competitiveness in S&T, they do suggest that the feared march to dominance will not lack significant challenges for these countries. Moreover, it may take longer for significant qualitative changes to occur than first imagined.

New approaches to conducting academic research across international borders may have a more fundamental impact on the near-term future. International educational joint ventures are becoming more prevalent, such as the Johns Hopkins-Nanjing program in Chinese and American studies, the Duke-Goethe executive M.B.A. program, and the MIT-Singapore alliance that offers dual graduate degrees in various engineering fields.[122]

Another new trend is the outsourcing portions of a research program to facilities in another country. In one such example, a Chinese professor at Yale runs a research center focused on genetics of human disease at his alma mater, Shanghai's Fudan University, in collaboration with faculty from both schools. The Shanghai Center has 95 employees and graduate students working in a large laboratory facility. Yale faculty, postdoctoral fellows, and graduate students visit often and attend videoconference seminars with scientists from both campuses. The Yale-based laboratory has increased its productivity thanks to the lower costs of conducting some of its research in China. At the same time, Chinese graduate students, postdoctoral fellows, and faculty receive on-the-job training from a world class scientist and his U.S. team.[123]

These international programs will hasten the virtual elimination of borders for knowledge transfers. They also will level the playing field for countries to entice their talented, foreign-educated citizens back home. Moreover, countries such as China are working hard on elevating the world status of their top universities to encourage talented students to train at home. These factors may significantly alter past patterns of migration and have a significant impact on the availability of trained S&E personnel in the United States.

[122] Levin, *supra*.
[123] *Id.*

APPENDIX C: DISRUPTIVE INNOVATIONS

Certain innovations have the potential to fundamentally alter the way the Intelligence Community and its partners operate around the globe. These innovations will have broad implications for everything from accelerating knowledge transfer to affecting the ability to operate in secret to altering the balances of economic and political power. To build a strategy to deal with these innovations, the Intelligence Community must understand the U.S. position in each of these fields and how these impacts may play out.

A study by RAND for the National Intelligence Council attempted to address the feasibility of many of these innovations. Table 1 lays out the conclusions. The letter "G" in parenthesis after the item indicates that these items are expected to have a global impact.

Table C-1. Technical and Implementation Feasibility of Illustrative 2020 Technology Applications

Table S.1
Technical and Implementation Feasibility of Illustrative 2020 Technology Applications

Technical Feasibility	Implementation Feasibility: Niche market only (– –)	May satisfy a need for a medium or large market, but raises significant public policy issues (–)	Satisfies a strong need for a medium market and raises no significant public policy issues (+)	Satisfies a strong need for a large market and raises no significant public policy issues (+ +)
Highly Feasible (+ +)	• CBRN Sensors on ERT (2,G)	• Genetic Screening (2,G) • GM Crops (8,M) • Pervasive Sensors (4,G)	• Targeted Drug Delivery (5,M) • Ubiquitous Information Access (6,M) • Ubiquitous RFID Tagging (4,G)	• Hybrid Vehicles (2,G) • Internet [for purposes of comparison] (7,G) • Rapid Bioassays (4,G) • Rural Wireless Comms (7,G)
Feasible (+)	• GM Animals for R&D (2,M) • Unconventional Transport (5,M)	• Implants for Tracking and ID (3,M) • Xenotransplantation (1,M)	• Cheap Solar Energy (10,M) • Drug Development from Screening (2,M) • Filters and Catalysts (7,M) • Green Manufacturing (6,M) • Monitoring and Control for Disease Management (2,M) • Smart Systems (1,M) • Tissue Engineering (4,M)	• Improved Diagnostic and Surgical Methods (2,G) • Quantum Cryptography (2,G)
Uncertain (U)	• Commercial UAVs (6,M) • High-Tech Terrorism (3,M) • Military Nanotechnologies (2,G) • Military Robotics (2,G)	• Biometrics as sole ID (3,M) • CBRN Sensor Network in Cities (4,M) • Gene Therapy (2,G) • GM Insects (5,M) • Hospital Robotics (2,M) • Secure Video Monitoring (3,M) • Therapies based on Stem Cell R&D (5,M)	• Enhanced Medical Recovery (3,M) • Immunotherapy (2,M) • Improved Treatments from Data Analysis (2,M) • Smart Textiles (4,M) • Wearable Computers (5,M)	• Electronic Transactions (2,G) • Hands-free Computer Interface (2,G) • *In-silico* drug R&D (2,G) • Resistant Textiles (2,G) • Secure Data Transfer (2,M)
Unlikely (–)	• Memory-Enhancing Drugs (3,M) • Robotic Scientist (1,M) • Super Soldiers (2,M)	• Chip Implants for Brain (4,M)	• Drugs Tailored to Genetics (2,M)	• Cheap Autonomous Housing (6,G) • Print-to-Order-Books (2,G)
Highly Unlikely (– –)	• Proxy-bot (3,M) • Quantum Computers (3,M)	• Genetic Selection of Offspring (2,M)	• Artificial Muscles and Tissue (2,M)	• Hydrogen Vehicles (2,G)

NOTE: For each technology, the parenthetical information indicates the number out of 12 societal sectors (water, food, land, population, governance, social structure, energy, health, economic development, education, defense and conflict, and environment and pollution) that can be impacted by the technology, and if the diffusion will be global (G) or moderated (M). For example, Hybrid vehicles affect two sectors and will have global diffusion.

Richard Silberglitt, et al., *The Global Technology Revolution 2020, In-Depth Analyses*, RAND, 2006, p. xix.

C.1 NANOTECHNOLOGY

The National Nanotechnology Initiative (NNI) defines "nanotechnology" as encompassing science, engineering, and technology

> ...related to the understanding and control of matter at the length scale of approximately 1 to 100 nanometers. However, nanotechnology is not merely working with matter at the nanoscale, but also research and development of materials, devices, and systems that have novel properties and functions due to their nanoscale dimension or components. [124]

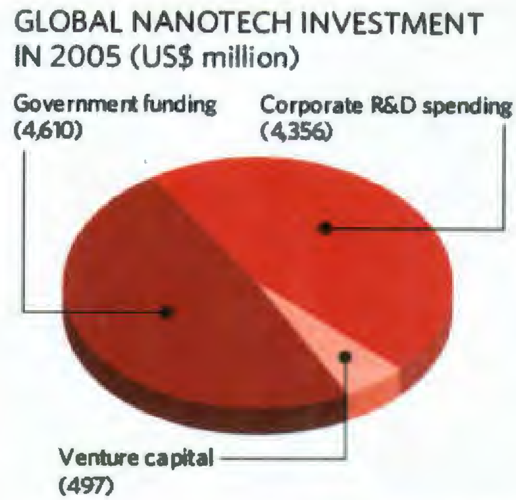
But the NNI distinguishes nanotechnology R&D from other research that may have achieved a "certain level of miniaturization or that operates at a nanometer-length scale." This can create certain confusions where nanoscale research intersects with biology.[125]

"'Nanotechnology' touches upon a broad array of disciplines, including chemistry, biology, physics, computational science, and engineering. Like information technology, nanotechnology has the potential to a virtually every industry, from aerospace and energy to healthcare and agriculture."[126]

The United States made a commitment to nanotechnology in 2000 with the establishment of the NNI. By 2005 funding for the NNI reached over $1 billion, providing support to 11 agencies. Forty centers and networks have been funded or are in the planning stages.

In 2005, worldwide spending for nanotechnology across all sectors totaled $9.5 billion, up 10 percent from 2004 (Figure C-1). Virtually every country that provides financial support for science and technology R&D has a nanotechnology initiative.

[124] PCAST, *supra*, 7.
[125] *Id.*
[126] *Ibid.*, 5.



Source: *Nature*, September 14, 2006 (Based on Lux Research)

Figure C-1. Global Nanotechnology Funding, 2005 ($ billions)

Of the $4.6 billion spent by governments on nanotechnology R&D in 2004, the United States led in absolute terms, with second-place Japan spending not even two-thirds as much as the United States (Figure C-2).

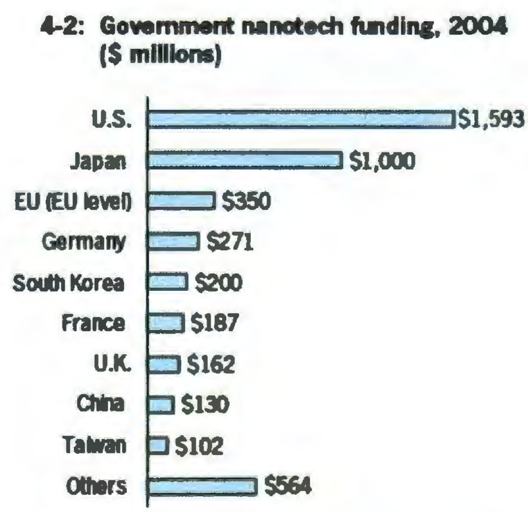


Figure C-2. Government Nanotechnology Funding, 2004 ($ millions)

It should be noted, however, that approximately $432 million of the U.S. amount shown in Figure C-2 was at the state level and went for initial purchases of equipment and construction of facilities, not to fund ongoing research. Thus, the state spending is more likely to consist of one-time capital expenditure than to represent sustained spending.[127] Removing these one-time expenditures would bring Japan's spending much closer to the U.S. figure.

One example of state-level initiative is the Albany NanoTech, which is home to five R&D centers and the College of Nanoscale Sciences and Engineering at the State University of New York, Albany. Albany NanoTech alone has attracted over $1 billion in private investment and has formed over 100 partnerships with other universities, federal laboratories, and industry. These programs have led to close relationships with major electronics firms such as IBM, ASML, Tokyo Electron, and International Sematech.[128] Because roughly two-thirds of the federal NNI funding flows to university researchers,[129] these state initiatives may not represent additional significant spending beyond the federal figures. Thus, although these state programs may have a significant impact on the future of nanotechnology in the United States, that impact is not easily captured in traditional government/industry spending measures. Table C-2 shows some additional examples of state-level activities.

[127] Nordan, *supra.*
[128] Floyd Kvamme, Partner Kleiner Perkins Caufield and Byers, Co-Chair, President's Council of Advisors on Science and Technology Policy, testimony before the House Committee on Science, Subcommittee on Research, June 29, 2005.
[129] Lane and Kalil, *supra.*

Table C-2. Nanotechnology R&D Infrastructure Investments at State Level

Table 2.
Nanotechnology R&D Infrastructure Investments at State Level

State	Recipient	Description	Partnership Model
AZ	Nano-bio research center	Research Infrastructure	University-State
CA	California Nanosystems Institute	Building Infrastructure	Metropolitan-State
FL	Center at University of South Florida	Faculty Recruitment & Infrastructure	University-State
GA	Center at Georgia Tech	Building & Research Infrastructure	
IL	Nanoscience Centers (Northeastern Univ., U. of IL, Argonne National Laboratory)	Building & Research Infrastructure	Non-profit-Metropolitan-Regional
IN	Nanotechnology Center at Purdue	Building Infrastructure	
NJ	Support at NJ Institute of Tech and photonics consortium	Building Infrastructure	State-Industry
NY	Nanoelectronics Center, Albany	Building & Research Infrastructure	University-State
OK	NanoNet	EPSCoR	University-Region
OR	ONAMI – Oregon Nano-Micro Interface Institute	Research Infrastructure	University-Industry
PA	Nanotechnology Center		Non-profit-University-State
SC	NanoCenter	Building Infrastructure	
SD	Center for Accelerated Applications at the Nanoscale	Research Infrastructure	UniUniversity-State
VA	Various institutions and Luna Innovations	Research Matching & Infrastructure	University-State
WA	University of Washington, Washington Tech Center	Clean Room Maintenance	University-State Partnership

Source: NSTC Report of the NNI Workshop on Regional, State and Local Initiatives in Nanotechnology, September 30-October 1, 2003 (2005). Note: The examples offered here provide a sampling of infrastructure investments by various U.S. States. This list is not comprehensive and does not include non-infrastructure investments.

Other estimates of spending by various national governments include those shown in Table C-3 and Figure C-3. It should be noted that the data may suffer from significant definitional issues and lack of access to accurate government spending figures from some countries. This may prevent true "apples to apples" comparisons. However, the trends incontrovertibly show significant increases in spending by all nations, particularly since 2000.

Table C-3. Estimated Government Nanotechnology R&D Investments, 1997–2004 ($ millions)

Table 1.
Estimated Government Nanotechnology R&D Investments in 1997-2004 ($ Millions)

Region	1997	1998	1999	2000	2001	2002	2003	2004	2005
EU	126	151	179	200	~ 225	~ 400	~ 650	~ 950	~ 1,050
Japan	120	135	157	245	~ 465	~ 720	~ 800	~ 900	~ 950
U.S.	116	190	255	270	465	697	862	989	1,081
Others	70	83	96	110	~ 380	~ [illegible]	~ 800	~ 900	~ 1,000
Total (% of 1997)	432 (100%)	559 (129%)	687 ([illegible])	825 (191%)	~ [illegible] (355%)	~ 2,350 (547%)	~ 3,100 (720%)	~ 3,700 ([illegible])	~ 4,100 ([illegible])

Source: M. Roco, National Science Foundation

Figure 1.
Government Nanotechnology R&D Investments in 1997-2004

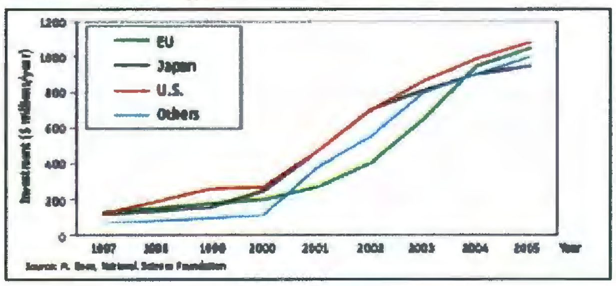


Figure C-3. Government Nanotechnology R&D Investments, 1997–2004

In reality, however, U.S. government spending is not keeping up with opportunities. When examining these trends it should be noted that the current administration's FY 2006 budget proposed a decrease in funding from the level of support provided by Congress in FY 2005.[130] The 2007 budget request is also less than the estimated 2006 spending. Thus, the U.S. figures over the next few years may show a reverse trend for U.S. spending, while foreign spending is expected to continue to rise. Researchers reported in 2005 that NSF received 48 proposals in its most recent solicitation for Nanoscale Science and Engineering Centers, but could fund only 6.[131]

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[130] *Id.*
[131] Lane and Kalil, *supra.*

Just as is true of overall S&T expenditures, the private sector, not government, accounts for the majority of nanotechnology spending in the United States (Figure C-4). The majority of corporate spending on nanotechnology R&D worldwide also occurred in the United States. Of the approximately 1,200 nanotech startups in 2004, half were in the United States. A 2005 study identified approximately 600 companies in the United States or with significant U.S. operations that are engaged in nanotechnology R&D, manufacture, sale, and/or use. Notably, 72.9 percent of these companies had been in business for less than 10 years.

Figure C-4. Corporate Nanotechnology R&D, 2004 ($ billions)

Venture capital investment in nanotech startups fell from $385 million in 2002 to $200 million in 2004, accounting for only 2 percent of nanotechnology funding in 2004. Venture capitalists who lost heavily in the Internet bubble may well be hesitant to commit more money until they can see "substantial exits."[132]

The United States spends more on an absolute basis for nanotech research than any other country, but it is falling behind Asian countries on a relative basis (Figure C-5). Between 2001 and 2004 the U.S. share of global government spending has dropped, although actual spending doubled from $465 million to $960 million. The $130 million in estimated government spending on nanotech in China equaled $611 million when

[132] Nordan, *supra*.

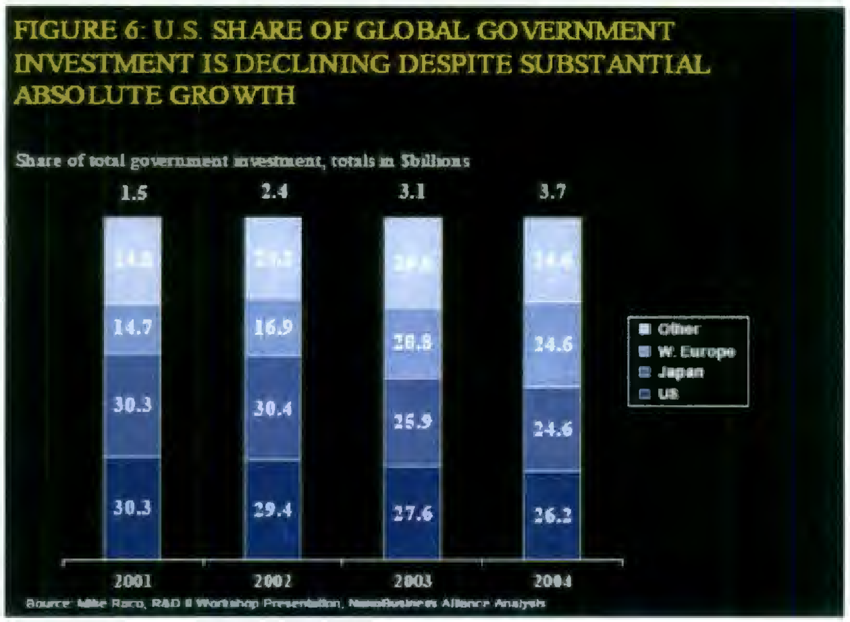


Figure C-5. U.S. Share of Global Government Investment

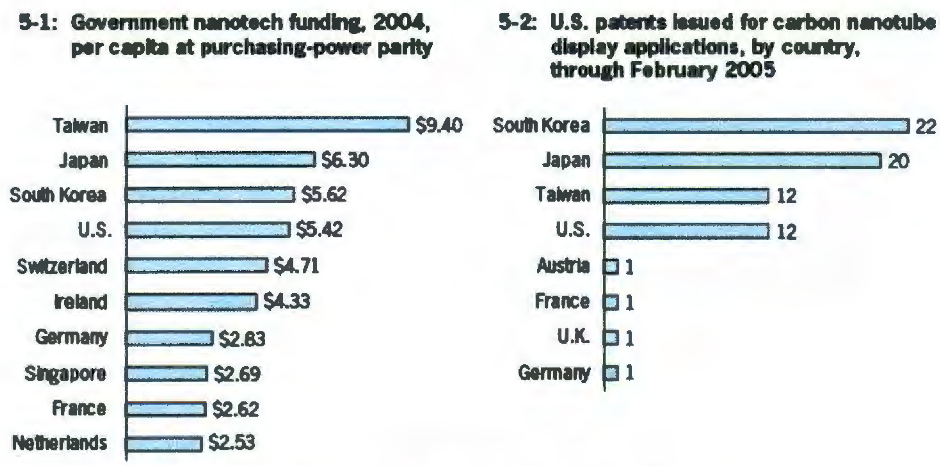
adjusted for purchasing power parity, 38 percent of U.S. expenditures. This placed China second, ahead of Japan and Germany. When spending levels are adjusted for purchasing power parity, the per capita spending in the United States is only fourth in the world.[133] In addition, some countries that the United States considers strategic threats, such as Iran, have nanotechnology programs.

Sean Murdock, executive director of the NanoBusiness Alliance, testified in June 2005 that the United States is currently leading the world in nanoscience but the "lead is narrow and we face stiff and accelerating competition." He further asserted that nanotechnology "will be a game changing technology" and is likely "to be the engine of innovation for the next fifty years."[134] At the same hearing, Matthew Nordan of Lux Research, Inc., testified that while the United States leads the world in nanotechnology today, "its position is tenuous." The President's Council of Advisors on Science and Technology reported in May 2005 that the trends in investment, publications, and patents all show a "steady erosion" in the United States' lead in nanotechnology (Figure C-6).

[133] *Id.*

[134] Sean Murdock, executive director of the NanoBusiness Alliance, testimony before the House Committee on Science, Subcommittee on Research, June 29, 2005.

Fig. 5: The Dominant U.S. Position in Nanotechnology Lies at Risk



Source: Published spending allocations and Lux Research analysis; U.S. Patent and Trademark Office searches

Figure C-6. The Dominant U.S. Position in Nanotechnology Lies at Risk

Moreover, although other nations may not be spending as much as the U.S. overall, they are choosing to concentrate their efforts in particular sectors to make significant advances in those sectors more quickly (Table C-4). For example, Korea and Taiwan are investing heavily in nanoelectronics, while Singapore and China are focusing on nano-biotechnology and nanomaterials.[135]

[135] Jim O'Connor, Motorola, testimony before the House Committee on Science, Subcommittee on Research, June 29, 2005.

Table C-4. Focus Areas of Government Investments in Nanotechnology

Table 3.
Focus Areas of Government Investments in Nanotechnology

Country	Materials/ Manufact.	Devices (including Electronics & Optics)	Energy & Environment	Biotech/ Medical	Instrument Development	Education
Argentina	X					
Australia	X	X	X	X		
Austria						
Belgium	X	X		X		
Brazil	X	X		X		
Taiwan	X	X		X		
Czech Republic	X	X		X		
European Union*	X	X	X	X	X	X
France	X			X		
Germany	X	X		X	X	
India	X	X		X	X	X
Ireland	X	X	X	X		
Israel	X			X		
Italy	X	X		X	X	
Japan	X	X	X	X	X	
Korea	X	X				
Mexico	X					
Netherlands	X	X		X	X	
New Zealand	X					
Romania	X			X		
South Africa	X		X	X		
Switzerland	X	X		X	X	
United Kingdom	X	X		X		
United States	X	X	X	X	X	X

Source: June 2004 International Dialogue on Responsible Research and Development of Nanotechnology. http://www.nanoandthepoor.org/international.php

Note *: While the EU as a whole is pursuing a broad program, individual EU countries (also shown here) have more targeted areas of research.

China is investing heavily in nanotechnology through the National 863 Hi-Tech R&D Plan and has opened three nanotechnology centers and over 20 university institutes, including the Shanghai Nanotech Promotion Center—a network of six nanotechnology R&D centers at Shanghai universities. In 2000 the Chinese Academy of Sciences (CAS) opened The Center for Nanotechnologies to unite over a dozen CAS institutes and several university laboratories.[136] In 2004 it was reported that the Chinese central government had budgeted about $240 million for nanotech projects between 2003 and 2007. In addition, at least as much had been

[136] Alexandr Nemets, "China's Nanotech Revolution," Association for Asian Research, August 23, 2004, www.asianresearch.org/articles/2260.html

budgeted by local Chinese governments. A year later the Chinese government announced that it was increasing its investment levels but did not specify by how much. As of 2005 it was reported that China had 3,000 researchers engaged in nanotechnology related programs and over 800 companies working in the nanotechnology field. According to reports from the Asian Technology Information Program (ATIP),

> China is especially strong in nanomaterials development. China's nanomaterials focus, its low cost of doing business, its talented labor pool, and its potentially large domestic market, could provide incentive for further investment by foreign corporations seeking to capitalize on nanomaterials development.[137]

In November 2002 the CAS launched a joint project with a U.S. company, Veeco Instruments, Inc., under which the CAS agreed to cooperate in running a nanometer technology center aimed at providing Chinese researchers access to Veeco-made nanotechnology instruments. At the opening of the center Veeco President Don Kania predicted that "China will gain the leadership position in nanotech."[138]

Although the impact of such investments is hard to quantify, researchers highlight two developments in China's quest for nanotechnology leadership. First, Chinese researchers are now publishing more research papers on nanotechnology. In fact, according to *The Scientist*, from January to August 2004 (the latest figures available at the time of publication), China produced 3,621 research papers on nanotechnology—more than any other country and 14 percent more than the United States. This must be seen in context; one source suggests that in terms of "high impact" publications the United States has stemmed its drop in share and still has over 50 percent of the annual high-impact publications (Figure C-7). Other sources do not support the claim that China has overtaken the United States in publications at any level of impact (Figure C-8).

[137] PCAST, *supra*.
[138] Nemets, *supra*.

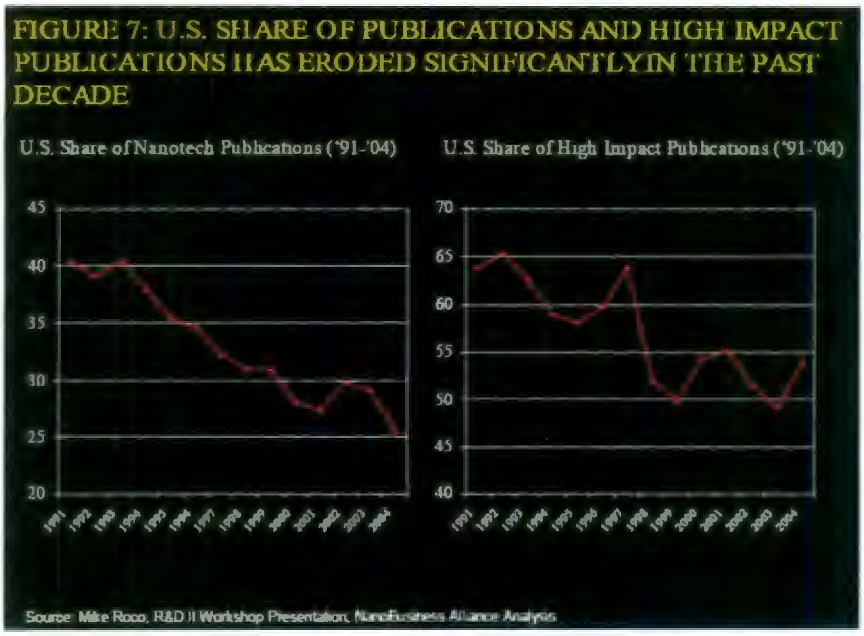


Figure C-7. U.S. Share of Publications and High-Impact Publications

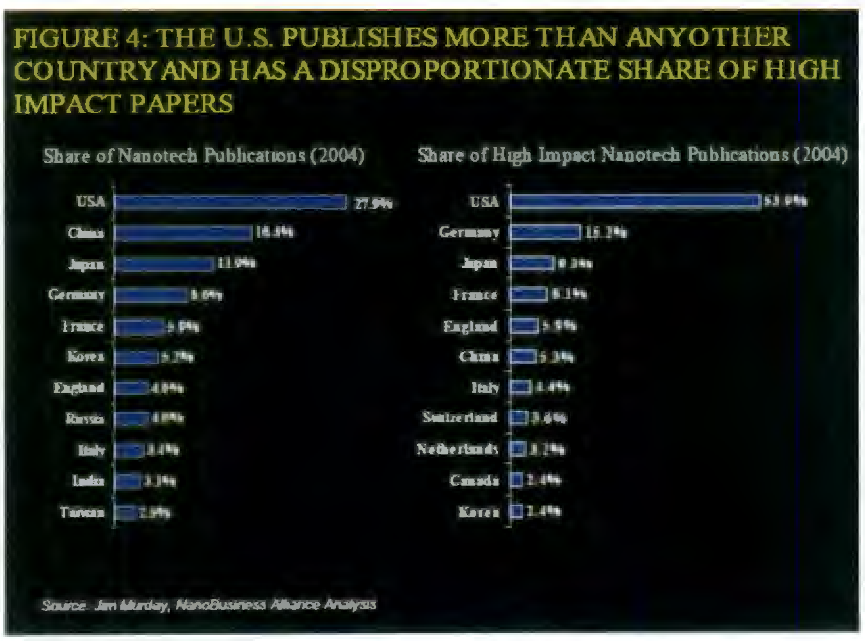


Figure C-8. U.S. Lead in Publications

Second, China promulgated its first batch of standards related to nanotechnology and is currently seeking to develop a complete set of standards to be adopted by the International Standards Organization and thus shape the future of nanotechnological development. The United States, Japan, and some European countries are working on their own set of standards to try to create a competitive/alternative framework for the future direction of nanotechnology.

Third, some industry leaders express concern that China's lax enforcement of intellectual property rights makes competition with China difficult, if not impossible. Chinese manufacturers are stressing their ability to deliver products identical to those of U.S. and European companies at prices 15–20 percent lower. Because they generally refuse to identify their production processes, some suspect that they are using Western patent filings "like recipe books."[139] As the National Nanotechnology Advisory Panel noted in its May 2005 report,

> While we all want the United States to benefit economically from nanotechnology as quickly as possible, it is critically important that the basic intellectual property surrounding nanotechnology be generated in and reside within [the United States]. Those who hold this knowledge will 'own' commercialization in the future.[140]

C.2 Biotechnology

The development of biotechnology around the world is likely to be very uneven (Table C-5 and Figure C-9). Some countries have opted for slower development because of concerns over ethical issues and environmental risks, whereas others do not share the same concerns and are adopting biotechnology more rapidly. For example, while Asian countries appear poised to move toward use of genetically modified foods and organisms, public sentiment and pending legislation are likely to pose a barrier to similar developments in the European Union.[141] The impossibility of containing knowledge within country borders as a result of the increasing flow of information, people, and resources means that cautious countries cannot control the actions of less cautious countries and/or entities. The emergence of significant private-sector investment around the globe for research in the areas of stem cells and cloning exemplifies this dilemma.

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[139] Nordan, *supra*.
[140] PCAST, *supra*, 3.
[141] Silberglitt, et al., *supra*.

Table C-5. Growth in Global Biotechnology, 2004–2005

Growth in global biotechnology, 2004–2005

	2005	2004	% change
Public company data			
Revenues ($m)	63,156	53,367	18%
R&D expense ($m)	20,415	19,542	4%
Net loss ($m)	4,388	6,270	-30%
Number of companies			
Public companies	671	645	4%
Private companies	3,532	3,522	0.3%
Public and private companies	4,203	4,167	1%

Source: Ernst & Young
The 2005 financials largely represent data from January 1, 2005 through December 31, 2005
The 2004 financials largely represent data from January 1, 2004 through December 31, 2004
Numbers may appear inconsistent because of rounding

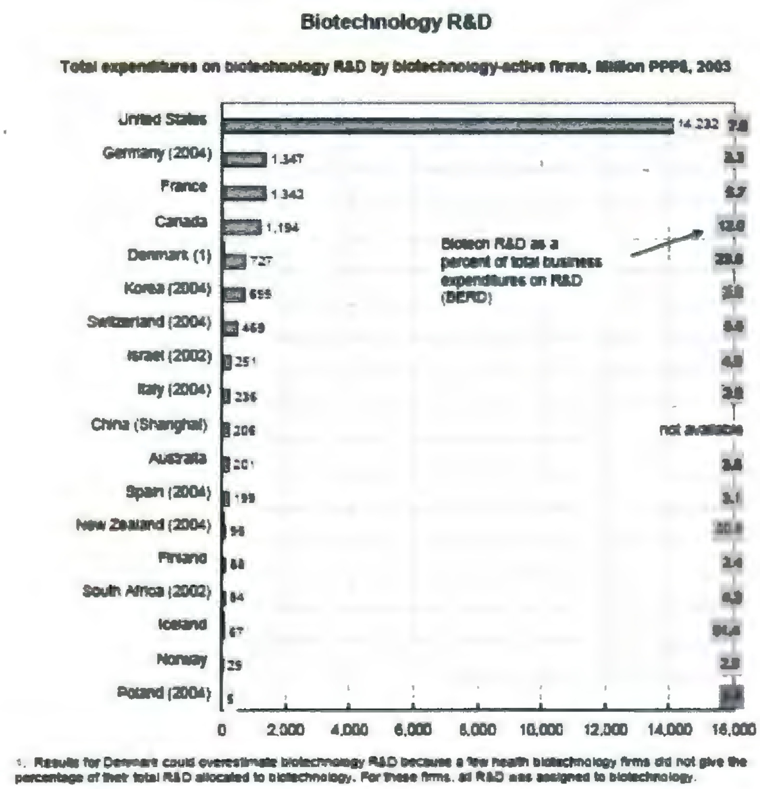
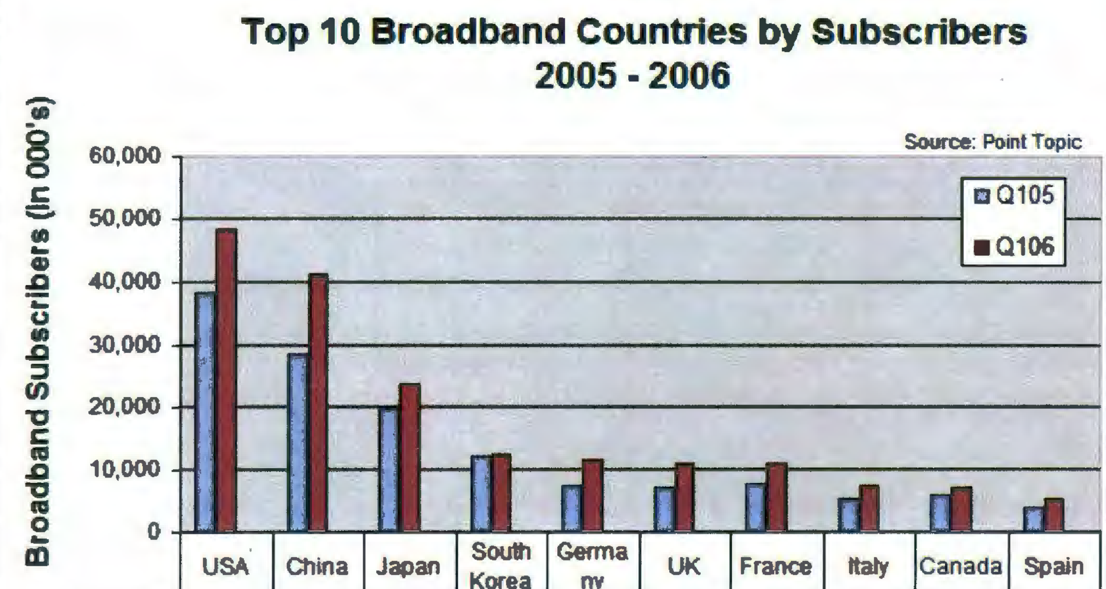


Figure C-9. Total Expenditure on Biotechnology R&D by Active Firms, 2003 ($ million ppp)

Appendix D: Worldwide Access to Information Is Expanding Rapidly

D.1 Broadband Usage

The rapid expansion of broadband access is greatly extending the ability to collect and share information around the world in mere seconds. As of the first quarter 2006 the United States still led in total number of broadband subscribers with over 48 million. China was in second place with over 41 million, and Japan was in third place with 23 million subscribers (Figure D-1).



	USA	China	Japan	South Korea	Germany	UK	France	Italy	Canada	Spain
Q105	38,004	28,307	19,838	12,087	7,536	7,116	7,669	5,208	5,889	3,736
Q106	48,311	41,196	23,701	12,459	11,449	10,833	10,821	7,394	7,105	5,322
Growth	27%	46%	19%	3%	52%	52%	41%	42%	21%	42%

Source: Point Topic

Figure D-1. Top 10 Broadband Countries by Subscribers Q1 2005–Q1 2006

If the growth in the number of subscribers continues at its current rate, China is expected to pass the United States sometime next year. It should be noted, however, that this growth rate has slowed significantly in the past two quarters. The growth rate from third quarter 2004 to third quarter 2005 was over 90 percent, but the growth rate from first quarter 2005 to first quarter 2006 was only 46 percent. It is uncertain whether this slowing is due to saturation of the most easily wired locations, government controls on Internet access in the country, different sources of data, or other unknown factors. However, one source, the analyst company Ovum, predicts continued growth at approximately 79 percent per year. If this prediction is accurate, China would reach 79 million subscribers sometime in 2007[142] and 139 million subscribers by 2010. The vast majority of current subscribers, 71 percent according to Ovum, use Digital Subscriber Line (DSL) access. Another 26 percent use Ethernet-based LANs (local area networks), primarily in high-density areas. There is little use of cable access even though China already has 128 million cable TV subscribers.

Despite these current figures, however, China still lags the United States significantly in household penetration, with only 8.62 percent of households having Internet access. While significantly higher than the Chinese percentage, the relative position of the United States is dropping due to higher growth rates in Sweden, Luxembourg, and the United Kingdom. South Korea still leads all countries with 83 percent broadband penetration, followed by Hong Kong with 80.98 percent, Iceland at 74 percent, Israel at 69.08 percent, and Taiwan at 64.65 percent (Figure D-2).

Broadband access via cellular/mobile networks promises to increase the number of broadband subscribers. Although second-generation (2G) cellular/mobile networks are able to provide data connectivity equivalent to slow dial-up links, they are not sufficient to provide truly mobile broadband wireless access. Third-generation (3G) mobile networks and "2.5G" enhancements for existing networks are adequate to provide packet-based communications that can reach broadband speeds of 200 kbps or better.[143] High-speed downlink packet access (HSPDA), also known as 3.5G, will require only incremental upgrading as opposed to replacement costs of other new technologies.[144]

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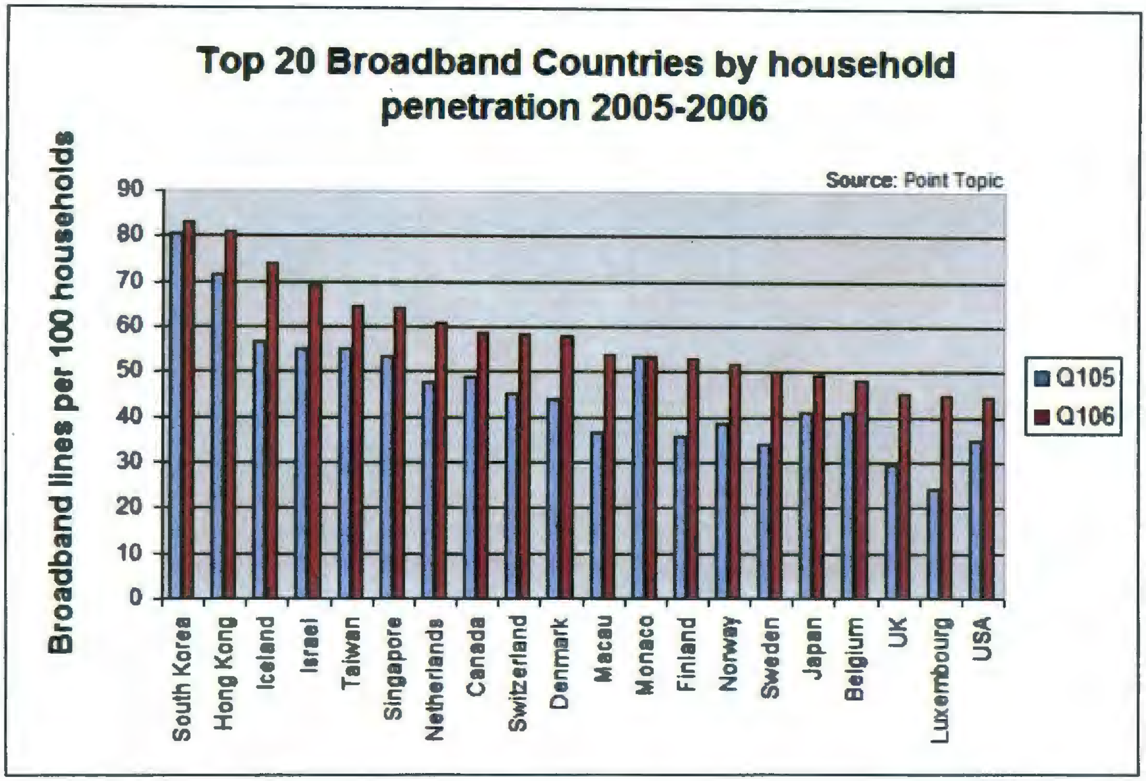
[142] One source suggests that the number of broadband users in China has already reached 77 million. *Sino Daily*, September 21, 2006. It is unclear, however, whether "subscribers" and "users" are the same thing so no conclusion can be drawn about whether the data sources are comparable.

[143] Burton Group, *supra*, 4–5.

[144] CNET Asia, April 24, 2006.



Source: Point Topic

Figure D-2. Top 20 Broadband Countries by Household Penetration Q1 2005 - Q1 2006

3G mobile data services are currently available in major metropolitan areas in Europe, Asia, and the United States. The 3G technologies—Evolution-Data Only Revision 0 (EV-DO Rev 0) for Code Division Multiple Access 2000 (cdma2000) and Universal Mobile Telecommunications System (UMTS) for Global System for Mobile Communications (GSM) carriers—provide downlink speeds equivalent to broadband (i.e., 200+ Kbps). Several vendors (including Hewlett-Packard, Dell, and Lenovo) are embedding 3G technology into their laptops. The next versions of 3G technologies—EV-DO Rev A and HSPDA—are likely to achieve "widespread metropolitan coverage" by the end of 2007, although uplink speeds are still fairly slow: 30 Kbps to 60 Kbps. Because voice revenues are declining, companies are looking to data services to offset these lower earnings. As a result, they are motivated to invest heavily in their networks and improve the available services.[145]

Even newer technologies are expected to fuel the expansion of such access into increasingly remote areas. One such technology, WiMax (also known as fourth-generation wireless or 4G), is expected to provide broadband access in rural areas not currently served by hardwire access.[146] WiMax comes in two versions: the fixed broadband system already in place in Europe (under IEEE standard 802.16d) and the mobile version (under IEEE standard 802.16e). The fixed version currently requires users to put a small receiver dish on their roof and connect it to a modem. This permits Internet access from antennas up to 10 kilometers away. The latter version of WiMax will provide high-speed Internet access, similar to current Wi-Fi technology, but over broad areas similar to those covered by mobile telephone networks.[147] Unlike current Wi-Fi, which has a range of 100 meters,[148] WiMax would function even when the user is many kilometers from a base station. The goal is for users to use a laptop, cell phone, or other "handheld gadget" without needing a cable or Wi-Fi "hotspot" and be able to surf the Internet or download music and movies as if they were using the fastest traditional broadband access.[149] WiMax will also link to the Internet "everything from digital cameras and music-players to sensors to household appliances. This will let people do things that are now technically difficult or prohibitively expensive, such as mobile video-conferencing or managing a building's lighting online."[150]

This technology has received recent boosts, with Sprint Nextel planning to spend $3 billion over the next two years to build a functioning U.S. network by 2008. Other key players in the development of the technology are Intel for chips, Motorola for equipment, and Samsung (the South Korean electronics company) for network infrastructure. Some have suggested, however, that WiMax would face a significant cost challenge from 3.5G technology in locations that have already invested in 3G infrastructure. In places where such technology is not already in place, particularly rural India, WiMax is expected to

[145] Gartner Group, "Mobile Data Services: So Many Choices," July 2006.
[146] WiMax stands for Worldwide Interoperability for Microwave Access and is based on IEEE 802.16e.
[147] "Surfing the Airwaves," *The Economist*, July 13, 2006.
[148] *New Scientist*, October 29, 2005
[149] "Wireless Networking May Soon Get Faster. Will Anyone Care?" *The New York Times*, September 26, 2006, www.nytimes.com/2006/09/26/business/26wireless.html
[150] "Wireless Broadband," *The Economist*, August 10, 2006.

flourish.[151] The 3.5G technology becomes especially attractive because at actual speeds WiMax offers little to no speed advantage for people with 3G smart phones or laptops with 3G modem cards that can be upgraded to 3.5G.[152]

Some have questioned whether 4G technology will succeed, given the expense of building such wireless networks and the relative cheapness of fixed-line access. But other countries are investing heavily, notably Japan, where the government has made leadership in 4G "a national goal" and is investing millions of dollars in research.

There are currently two competing 4G standards. The Japanese company NTT DoCoMo is championing an alternative version of 4G to WiMax.[153] Qualcomm and Ericsson are pursuing the same route as NTT DoCoMo. Meanwhile Samsung has assembled a team of 170 engineers, "most with doctorates from top universities in the United States,"[154] and spent over $1 billion on research into the WiMax approach. Samsung has already demonstrated a prototype that was used during a bus ride to show that the system worked over distance and while in motion.[155]

The cost tradeoff between this type of technology versus fixed line will also be significantly different in countries where fixed-line access is not yet widely available. Thus, the primary demand may come from countries where this technology will be the first to offer broadband access to remote areas rather than replacing existing technology. One source has indicated that the IEEE 802.16 2004 version of WiMax "is being adopted by carriers in developing countries as their primary means for providing broadband services, by competitive carriers globally to penetrate new markets, and by large incumbent carriers to extend their broadband networks into rural areas."[156]

A further effort that will push broadband access to more remote areas is the development of a windup laptop that will cost only $100 to manufacture. This machine, developed by MIT researchers, will come with batteries that can be recharged using a crank, thus avoiding the need for constant charging or connection to a power grid. It will have a 500

[151] CNET Asia, April 24, 2006
[152] *New Scientist*, October 29, 2005
[153] This alternative is based on IEEE 802.20.
[154] "Wireless Networking May Soon Get Faster. Will Anyone Care?," *supra*.
[155] *Id.*
[156] "Broadband Strategies for the Fixed Market," report abstract, June 1, 2006, available at www.marketresearch.com/map/prod/1300373.html

megahertz processor and only 1 gigabyte of memory, but include built-in wireless networking. A non-profit company formed by MIT to market the laptop hopes to build more than 100 million of these machines by 2007. They will not be sold commercially, but only to governments in developing countries for distribution to their nation's children.[157]

D.2 CELLULAR TELEPHONES

The significant increase in mobile phone penetration around the world parallels the rapid expansion of broadband and its supporting networks. China currently has 430 million cell phone subscribers. In August of this year this number increased by 5.19 million. India has 123 million subscribers to date, but has become the fastest-growing mobile market in the world, having added a net 5.9 million subscribers in August alone.

The biggest impact of cell phone growth is being seen in countries where landlines were never installed in significant regions and where installing them would be prohibitively expensive.[158] As of December 2005, more than 2 billion people had cell phones. It is estimated that there will be 3 billion cell phone users worldwide by end of 2008. China alone is expected to reach the 600 million mark by 2009.

Mobile phones are beginning to dominate over landlines. In March 2006 64 percent of the phones in service in India were cell phones. Of the new telephone subscriptions that month in India, 94 percent were solely for mobile phones.[159] In 2005 there were 1.26 billion land phone lines compared to the 2.14 billion cell phone subscribers worldwide. Eighty percent of the people in the world currently live in an area with cell phone reception.[160]

As a result, cell phone penetration figures continue to climb (Table D-1). As of 2005, 68 percent of the people in the United States had a cell phone subscription. Other countries had significantly higher figures.

[157] NewScientist.com News Service, *supra*.

[158] "Mobile Phone Proliferates, A Hallmark of New India," *The New York Times*, September 15, 2006, Section C, p. 4.

[159] "Cell Phone Subscriptions Surge in India," *News.com*, April 10, 2006, available at http://news.com.com/Cell+phone+subscriptions+surge+in+India/2110-1037_3-6059482.html

[160] "Recycled Cellphones Help Drive Third World Wireless Boom," *USA Today*, August 20, 2006, available at www.usatoday.com/tech/wireless/phones/2006-08-20-cellphone-recycling_x.htm (Statistics provided by International Telecommunications Union).

Table D-1. Cell Phone Penetration

CELL PHONE FACTS

Cell phone subscribers by country, 2005 (cell phones per 100 people).

- **Algeria**: 13.7 million (42).
- **Argentina**: 22.1 million (57).
- **Bangladesh**: 9 million (6).
- **Britain**: 61.1 million (102).
- **Canada**: 16.6 million (51).
- **Chad**: 210,000 (2).
- **China**: 393.4 million (30).
- **France**: 48.1 million (79).
- **Germany**: 79.2 million (96).
- **Guatemala**: 3.2 million (25).
- **India**: 76 million (7).
- **Japan**: 94.7 million (74).
- **Kenya**: 4.6 million (13).
- **Mexico**: 47.5 million (44).
- **Russia**: 120 million (84).
- **South Africa**: 31 million (65).
- **United States**: 201.6 million (68).
- **World**: 2.14 billion (32).

Source: International Telecommunication Union

By 2006, 30 countries had a penetration rate of over 100 percent (Table D-2). It is expected that by the end of 2006 that number will have reached 40.

Table D-2. The 30 Countries With More Than One Cell Phone Per Person

Penetration (%)	**Mar-06**
Turks & Caicos Islands	161.8
Aruba	150.8
Luxembourg	140.7
Lithuania	139.9
Cayman Islands	136.4
Netherlands Antilles	134.0
Grenada	133.3
Israel	125.9
Italy	122.4
Cyprus	121.5
Macau	121.3
Bahrain	117.8
Greece	114.7
Czech Republic	114.0
UAE	113.9
Jersey	113.6
Sweden	112.5
Hong Kong	110.8
UK	110.1
Estonia	108.6
Spain	108.0
Austria	107.3
Ireland	107.0
Norway	106.1
Antigua & Barbuda	104.6
Iceland	103.3
Finland	103.1
Portugal	101.3
Kuwait	101.1
Singapore	101.0
Source: research firm Informa Telecoms & Media	

Despite the rapidly changing nature of the cellular telephone industry, R&D spending by the telecommunications giants fell between 2000 and 2004, the latest year for which data were available. In 2000 the top four R&D spenders in the technology sector were telecommunications companies: Ericsson, Lucent, Motorola, and Nortel, together accounting for nearly $20 billion in R&D spending. By 2004 their combined spending had dropped to $9 billion. Lucent, parent company of Bell Labs, fell from number 6 among the overall top 100 spenders in 2000 to number 71 in 2004 after cutting its R&D spending five years in a row. In 2004 Swedish-based Ericsson cut its R&D spending 23 percent, spending $873 million less than in the prior year. That same year Motorola cut its spending by $711 million, a nearly 19 percent decrease from the prior year. The only top telecommunications company to hold its spending relatively steady was the Finnish company Nokia, which cut its spending less than one percent. As a result, it was the only telecommunications company in the top four of the technology sector companies in 2004.[161]

The drop in spending by these companies is expected to continue at least through 2006, with Nortel expected to decrease its R&D spending in 2006 by 17 percent from its 2005 levels. Lucent Technologies was expected to decrease its 2006 spending by 6 percent from the previous year. One notable exception is Tellabs, which is expected to increase its spending by 12 percent from the previous year, although it will still spend less than half of what Lucent spends this year.[162]

Despite the falling R&D spending cell phones are becoming more complicated, with more features. Many of them are small computers that may include a larger color screen and a built-in camera. They can send and receive text messages and serve as an alarm clock, calendar, game player, music player, or FM radio. Some have satellite positioning functions or may be able to record and play video clips.[163] These new devices are at the intersection of three key industries: communications devices, computers, and consumer electronics, and are the best-selling devices in all three of these categories. Some predict that increased processing power, memory bandwidth, and capacity mean that the total semiconductor memory content of all mobile devices sold yearly will equal that of personal computers by 2007.[164]

The way cell phones are being developed and manufactured has changed significantly. Due to the variety of features, colors, sizes, and shapes, the number of models introduced in a year has risen from 4 or 5 per year to 20 to 30 models. Although China has traditionally offered the

[161] "IEEE Spectrum R&D 100," *IEEE Spectrum*, December 2005.
[162] "2006 R&D Funding Improves Amid Increasing Restraints," *R&D Magazine*, January 2006.
[163] "Battling," *supra*.
[164] "Memory Technology in Mobile Devices—Status and Trends," November 9, 2005.

lowest labor costs for phone production, this has changed due to overall considerations. Now equipment manufacturers are opening plants in India, Brazil, Mexico, and Russia, where proximity to the locations where the phones will be sold and used, service, and flexibility offsets labor costs.[165]

Traditionally a few vertically integrated companies such as Nokia, Motorola, and Ericsson dominated the industry, since making mobile phones required expertise in a broad range of areas, including the design of radio chips and software, integration of electronic components, and case styling. Manufacturers had to be able to produce large quantities efficiently and promote products to consumers effectively. They also needed to build the large and complex base stations used to provide coverage. These requirements presented large barriers to entry that the usual low-cost electronics firms could not surmount.[166]

Those barriers have fallen in recent years, resulting in a completely new industry structure. Hardware and software have become commoditized. Radio chips and the necessary software can be purchased off the shelf. A number of small firms have sprung up that specialize in handset design, chip design, testing, and/or software. Manufacturing can be outsourced to electronic-manufacturing services firms. Some of these firms, called original design manufacturers (ODMs), have begun to design as well as build handsets.

Most of the largest ODMs are Taiwan-based, including BenQ, Arima, and Compal; others are in China and South Korea. They design and build the handsets for well-known companies that add their branding to the finished telephone and sell it as their own. In fact, the biggest ODM customers are the big-name companies such as Sony Ericsson (a handset joint venture between Sony in Japan and Ericsson of Sweden), Motorola, Siemens, Toshiba, and Panasonic. The new ODMs are disrupting the industry's previous order.[167] The rise of ODMs has allowed traditional handset companies to fill product line gaps quickly and cheaply, reduce R&D spending, and reduce risks from supply and demand swings.

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[165] Mitch Schoch, "Handset Manufacturing: Not a Simple Endeavor," *Surface Mount Technology*, **20**(5), May 2006, 29–30.
[166] "Battling," *supra*.
[167] *Id.*

Motorola and Sony Ericsson outsource 35 percent of their manufacturing and no longer design their own radio chips.[168]

The challenge for the largest companies, particularly Nokia and Motorola, is that they continue to plan to compete in every market worldwide. Their smaller competitors, however, intend to "cherry pick" certain markets and product niches. ODMs have already claimed 20 percent of the handset market in Taiwan and are targeting certain countries in central Europe.[169]

D.3 INTERNET STANDARDS

Standards for Internet use are also undergoing change. The next generation of the Internet Protocol, IPv6, is gaining momentum in South Asia and will be supported in Windows Vista. The new protocol will provide a greater supply of Internet addresses, improved configuration capabilities, mandatory support for IP security and quality of service, and simpler merging of networks. At a meeting of the Open Source Intelligence Forum in October 2006, Major General (ret.) Dale Meyerrose, chief information officer of the Office of the Director of National Intelligence (ODNI), stated that "the DoD and ODNI published a joint strategy to move to Internet Protocol version 6 in June. Additionally, Defense modified a number of its contracts, specifically those around net-centric services, so ODNI could use them more easily."[170]

Although operators in Asia have been ordered to support IPv6, U.S. IT managers have not acted to adopt the standard. Some have suggested that lack of expertise and deployment of IPv6 could hurt U.S. technical leadership in the Internet. Further, if international web sites cannot be accessed with IPv4 products, this could cause problems for U.S. enterprises.[171]

Others argue, however, that organizations other than government agencies or contractors required to adopt IPv6 should defer deploying it. They assert that arguments regarding IPv4 address space exhaustion and address inequity are "grossly exaggerated." They also claim that there is no evidence that IPv6 will enhance quality of service or network security compared to IPv4 services that have implemented IP security (IPsec) and

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168 *Id.*
169 *Id.*
170 Jason Miller, "Intel IT Is Coming Together," *Washington Technology*, October 20, 2006.
171 "IPv6 Still Gets No Respect in the United States," Eweek.com, June 15, 2006.

diffserv. They also dismiss the desirability of auto-assignment of addresses compared to Dynamic Host Configuration Protocol (DHCP) implementations, particularly in Active Directory environments. Finally, they argue that elimination of Network Address Translation (NAT) is not necessarily desirable because NAT contributes to many network security solutions.[172]

[172] Burton Group, "IPv6: Unmasked," February 2006.

Appendix E: Acronyms and Abbreviations

ARPA	Advanced Research Projects Agency
ATP	Advanced Technology Panel
CDMA	Code Division Multiple Access
CNGI	China's Next-Generation Internet
DARPA	Defense Advanced Research Projects Agency
DNI	Director of National Intelligence
DoD	Department of Defense
DSLAM	Digital Subscriber Line Access Multiplexer
EU	European Union
GSM	Global System for Mobile Communications
HUMINT	human intelligence
iARPA	intelligence Advanced Research Projects Agency
IC	Intelligence Community
IEEE	Institute of Electrical and Electronics Engineers
IPDSLAM	Internet Protocol Digital Subscriber Line Access Multiplexer
IPv	Internet Protocol version
ISB	Intelligence Science Board
IT	information technology
NGN	next-generation network
NIH	National Institutes of Health
NNI	National Nanotechnology Initiative
NS&E	natural sciences and engineering
NSF	National Science Foundation
ODM	original design manufacturer
ODNI	Office of the Director of National Intelligence
OECD	Organisation for Economic Cooperation and Development
R&D	research and development
S&E	science and engineering
S&T	science and technology
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
UMTS	Universal Mobile Telecommunications System
VoIP	voice over Internet Protocol