THE TASK FORCE
ON THE FUTURE OF AMERICAN INNOVATION

Innovation is America's Heartbeat

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THE KNOWLEDGE ECONOMY: IS THE UNITED STATES LOSING ITS COMPETITIVE EDGE?

BENCHMARKS OF OUR INNOVATION FUTURE

February 16, 2005

Agilent Technologies, ASTRA, American Chemical Society, American Electronics Association, American Mathematical Society, American Physical Society, Association of American Universities, Computing Research Association, Computing Technology Industry Association, Computing Systems Policy Project, Council on Competitiveness, Hewlett-Packard, Intel, Lucent, Materials Research Society, Microsoft, National Association of Manufacturers, NASULGC, The Science Coalition, Semiconductor Industry Association, Southeastern Universities Research Association, Texas Instruments

Introduction

For more than half a century, the United States has led the world in scientific discovery and innovation. It has been a beacon, drawing the best scientists to its educational institutions, industries and laboratories from around the globe. However, in today's rapidly evolving competitive world, the United States can no longer take its supremacy for granted. Nations from Europe to Eastern Asia are on a fast track to pass the United States in scientific excellence and technological innovation.

The Task Force on the Future of American Innovation has developed a set of benchmarks to assess the international standing of the United States in science and technology. These benchmarks in education, the science and engineering (S&E) workforce, scientific knowledge, innovation, investment and high-tech economic output reveal troubling trends across the research and development (R&D) spectrum. The United States still leads the world in research and discovery, but our advantage is rapidly eroding, and our global competitors may soon overtake us.

Research, education, the technical workforce, scientific discovery, innovation and economic growth are intertwined. To remain competitive on the global stage, we must ensure that each remains vigorous and healthy. That requires sustained investments and informed policies.

Federal support of science and engineering research in universities and national laboratories has been key to America's prosperity for more than half a century. A robust educational system to support and train the best U.S. scientists and engineers and to attract outstanding students from other nations is essential for producing a world-class workforce and enabling the R&D enterprise it underpins. But in recent years federal investments in the physical sciences, math and engineering have not kept pace with the demands of a knowledge economy, declining sharply as a percentage of the gross domestic product. This has placed future innovation and our economic competitiveness at risk.

To help policymakers and others assess U.S. high-tech competitiveness and the health of the American science and engineering enterprise, we have identified key benchmarks in six essential areas—education, the workforce, knowledge creation and new ideas, R&D investments, the high-tech economy, and specific high-tech sectors. We conclude that although the United States still leads the world in research and discovery, our advantage is eroding rapidly as other countries commit significant resources to enhance their own innovative capabilities.

It is essential that we act now; otherwise our global leadership will dwindle, and the talent pool required to support our high-tech economy will evaporate. As a recent report by the Council on Competitiveness recommends, to help address this situation the federal government should:

> *Increase significantly the research budgets of agencies that support basic research in the physical sciences and engineering, and complete the commitment to double the NSF budget. These increases should strive to ensure that the federal commitment of research to all federal agencies totals one percent of U.S. GDP.*[1]

This is not just a question of economic progress. Not only do our economy and quality of life depend critically on a vibrant R&D enterprise, but so too do our national and homeland security. As the Hart-Rudman Commission on National Security stated in 2001:

> *…[T]he U.S. government has seriously underfunded basic scientific research in recent years… [T]he 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.*[2]

In the post-9/11 era especially, we should heed this warning.

1 *Innovate America*, Council on Competitiveness, December 2004, p. 32 www.compete.org/pdf/NII_Final_Report.pdf

2 *Road Map for National Security: Imperative for Change*. Phase III Report of the U.S. Commission on National Security/21st Century, January 2001, p. ix www.au.af.milau/awc/awcgate/nssg/

Education Benchmarks

Signs of Trouble

- Undergraduate science and engineering (S&E) degrees within the United States are being awarded less frequently than in other countries. For example, the ratio of first university degrees in natural sciences and engineering (NS&E) to the college-age population in the U.S. is only 5.7 degrees per 100. Some European countries, including Spain, Ireland, Sweden, the United Kingdom, France and Finland, award between 8 and 13 degrees per 100. Japan awards 8 per 100, and Taiwan and South Korea each award about 11 per 100.[3]

- As other nations commit significant resources to S&E education, the U.S. share of worldwide undergraduate S&E degrees awarded annually has dropped. In 2000, Asian universities accounted for almost 1.2 million of the world's S&E degrees and European universities (including Russia and Eastern Europe) accounted for about 850,000 S&E degrees, while North American universities accounted for only about 500,000 degrees [4]

- The United States has a smaller share of the worldwide total of S&E doctoral degrees awarded annually than both Asia and Europe. In fact, in 2000, about 89,000 of the approximately 114,000 doctoral degrees earned worldwide in S&E were earned outside the United States.[5]

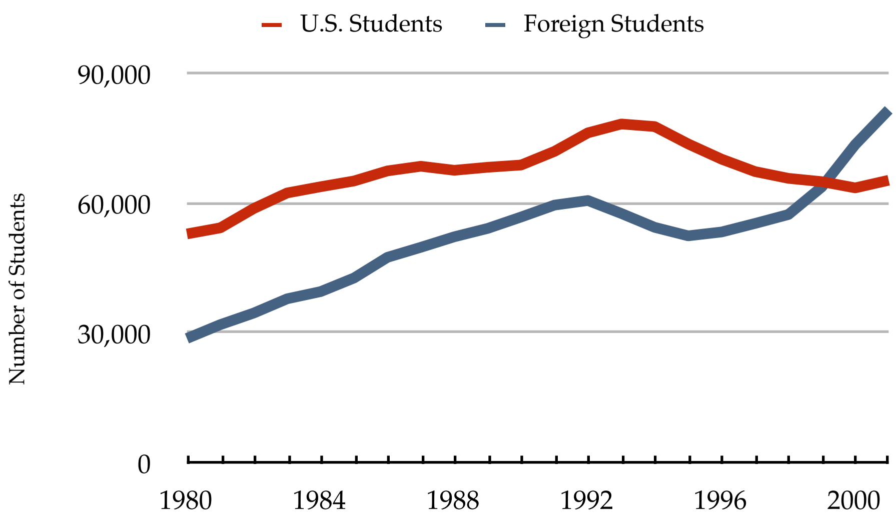
3 NSF Ind. 2004, Fig. 2-34 http://www.nsf.gov/sbe/srs/seind04/c2/fig02-34.htm

4 NSF Ind. 2004, Fig 2-33 http://www.nsf.gov/sbe/srs/seind04/c2/fig02-33.htm

5 NSF Ind. 2004, Appdx. Table 2-36 http://www.nsf.gov/sbe/srs/seind04/append/c2/at02-36.xls

- The proportion of U.S.-citizens in S&E graduate studies within the U.S. is declining. From 1994 to 2001, graduate S&E enrollment in the U.S. declined by 10 percent for U.S. citizens but increased by 25 percent for foreign born students. In 2001 approximately 57 percent of all S&E postdoctoral positions at U.S. universities were held by foreign born scholars.[6]

U.S. GRADUATE INSTITUTIONS: FOREIGN STUDENTS OUTNUMBER U.S. STUDENTS



Source: National Science Foundation, *Graduate Students and Postdoctorates in Science and Engineering: Fall 2001*, Tables 8-9. Compiled by the APS Office of Public Affairs.

6 NSF Ind. Appdx. Table 2-12 http://www.nsf.gov/sbe/srs/seind04/c2/c2h.thml, http://www.nsf.gov/sbe/srs/seind04/append/c2/at02-12.xls

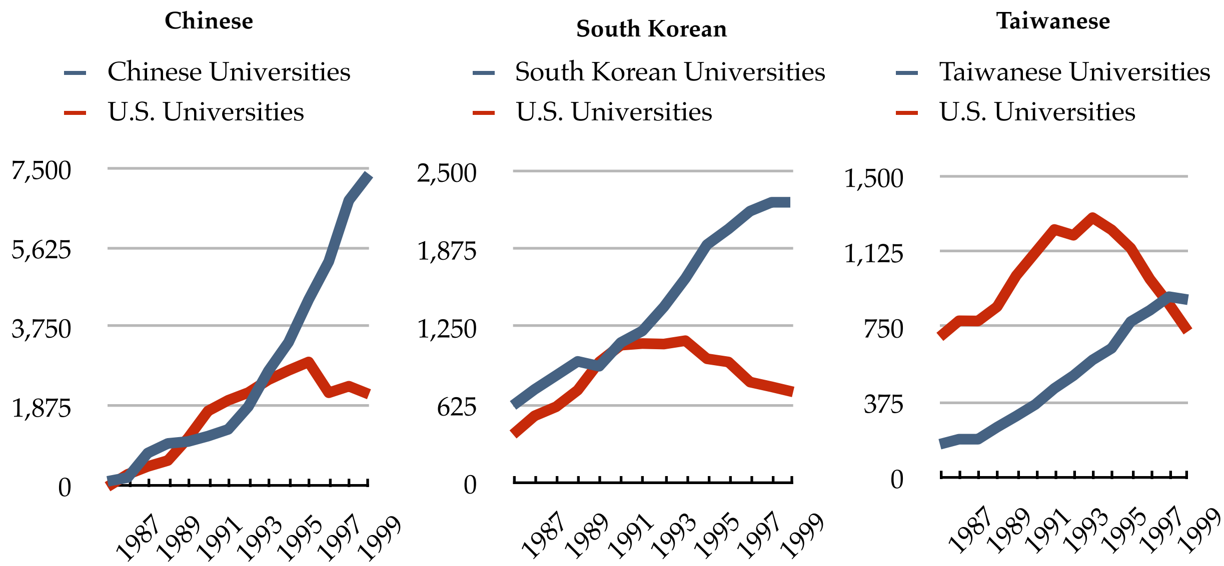
Workforce Benchmarks

Signs of Trouble

- Asian students are less likely to study in the U.S. From 1994 to 1998, the number of Chinese, South Korean, and Taiwanese students who chose to pursue their Ph.D.s at U.S. universities dropped 19 percent (from 4,982 to 4,029). At the same time, the number who chose to pursue their Ph.D.s at universities in their own countries nearly doubled (from 4,983 to 9,942). This indicates that these countries are quickly growing their own higher educational capabilities.

ASIAN PHD. STUDENTS ARE STAYING AT HOME

(1986 - 1999)



Source: National Science Foundation, *Science and Engineering Indicators 2002*, Appendix Table 2-41.
Adapted from Diana Hicks, "Asian countries strengthen their research," *Issues in Science and Technology*, Summer 2004.
Compiled by the APS Office of Public Affairs.

- Since 1980, the number of S&E positions in the U.S. has grown at almost five times the rate of the U.S. civilian workforce as a whole. However, the number of S&E degrees earned by U.S. citizens is growing at a much smaller rate, slightly less than the growth in the total U.S. civilian workforce and much less than the rate of growth in the number of S&E positions available.[7]

- There are rapidly increasing retirements from the S&E field, leading to a potential shortage in the S&E labor market. For example, more than half of those with S&E degrees in the workforce are age 40 or older. Unless more domestic college-age students choose to pursue degrees in critical S&E fields, there is likely to be a major shortage in the high-tech talent required by the U.S. defense industry, key federal

[7] NSF Ind. 2004, Fig 3-1 http://www.nsf.gov/sbe/srs/seind04/c3/fig03-01.htm & NSF Ind. Fig. O-15 http://www.nsf.gov/sbe/srs/seind04/c0/fig00-15.htm

research and national defense agencies (e.g. the Department of Defense, Department of Energy and NASA) and the national laboratories.[8]

- There is increasing global competition in the S&E labor market. Between 1993 and 1997 the Organisation for Economic Development countries increased their number of S&E research jobs by 28 percent, almost twice the 15 percent increase in S&E research jobs in the United States.[9]

8 NSF Ind. 2004, Overview, "Retirements and Demographic Shifts," http://www.nsf.gov/sbe/srs/seind04/c0/c0s1.htm

9 NSF Ind. 2004, Ch. 3, "Researchers in OECD countries, by country/region, 1993, 1995 and 1997," fig. 3-29. http://www.nsf.gov/sbe/srs/seind04/c3/fig03-29.htm

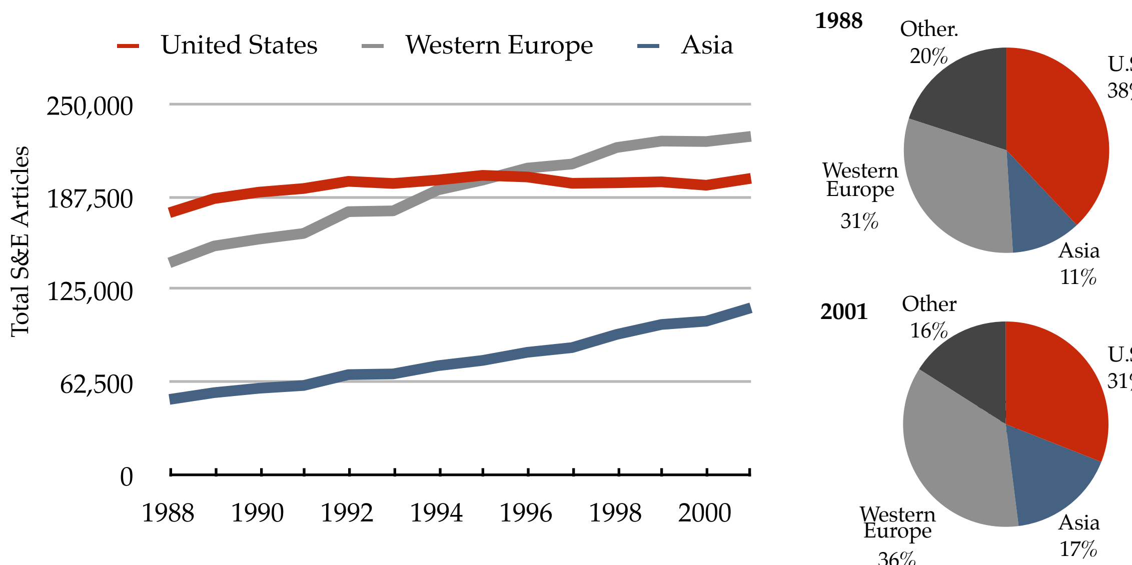
Knowledge Creation and New Ideas Benchmarks

Signs of Trouble

- The U.S. share of S&E papers published worldwide declined from 38 percent in 1988 to 31 percent in 2001. Europe and Asia are responsible for the bulk of growth in scientific papers in recent years. In fact, the U.S. output was passed by Western Europe in the mid-nineties, and Asia's share of the total is rapidly growing.[10]

- From 1988 to 2001 the U.S. increased its number of published S&E articles by only 13 percent. In contrast, Western Europe increased its S&E article output by 59 percent, Japan increased by 67 percent and countries of East Asia, including China, Singapore, Taiwan, and South Korea, increased by 492 percent. Though both Japan and East Asia started from a far smaller base in 1988, and still do not publish as many articles as the U.S., their growth rate is dramatic.[11]

S&E ARTICLES: U.S. ALREADY PASSED BY WESTERN EUROPE, ASIA RAPIDLY CLOSING



Source: National Science Foundation, *Science and Engineering Indicators 2004*.Appendix Table 5-35.
Compiled by the APS Office of Public Affairs.

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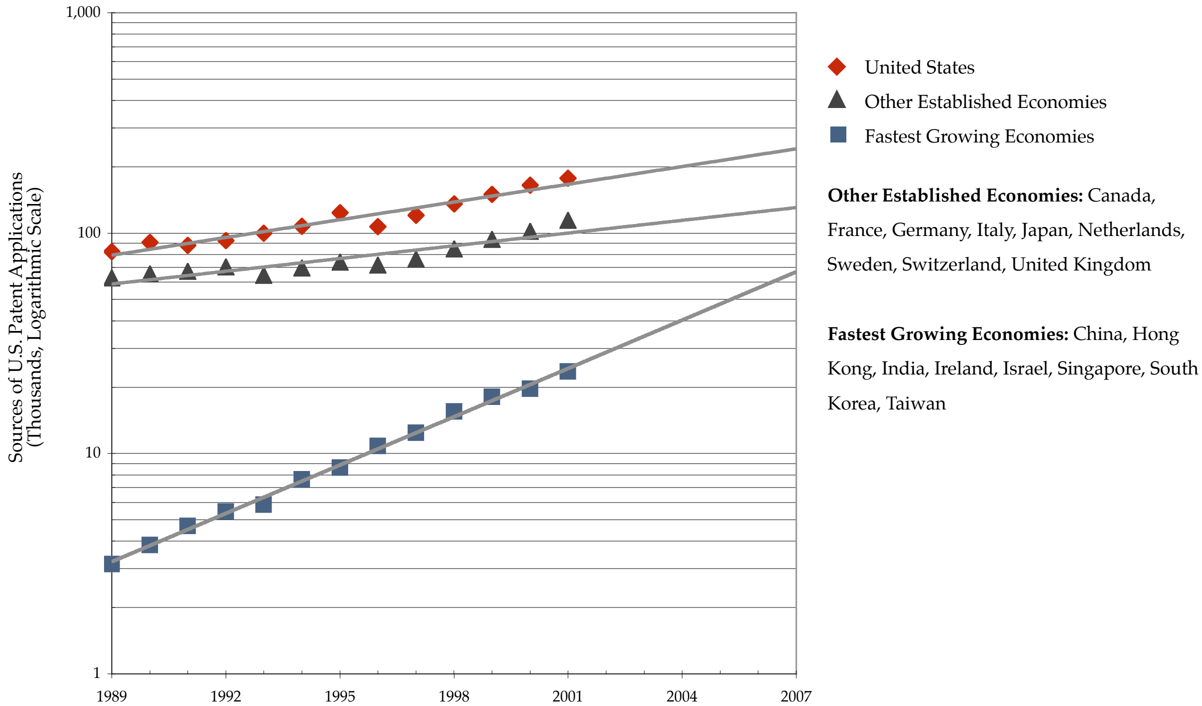
10 NSF Ind. 2004, Fig. 5-30 http://pubs.acs.org/cen/science/8224/pdf/8224sci2.pdf

11 NSF Ind. 2004, Appdx. Table 5-35 http://www.nsf.gov/sbe/srs/seind04/append/c5/at05-35.xls

- U.S. Patent applications from the Asian countries of China, India, Singapore, South Korea, and Taiwan grew by 759 percent from 1989 to 2001. Patent applications from the U.S. during the same period grew more slowly at 116 percent (though, as with the above, it should be mentioned that the Asian countries started out at a much lower base level).[12]

U.S. PATENT APPLICATIONS: FASTEST GROWING ECONOMIES GAINING ON U.S. RAPIDLY



Source: National Science Foundation, *Science and Engineering Indicators 2004*, Appendix Table 6-11.
Compiled by the APS Office of Public Affairs

- The U.S. share of worldwide citations is shrinking. Whereas in 1992 the U.S. share of citations was 52 percent, by 2001 it had declined to 44 percent of the worldwide total.[13]

12 NSF Ind. 2004, Appdx. Table 6-11 http://www.nsf.gov/sbe/srs/seind04/append/c6/at06-11.xls

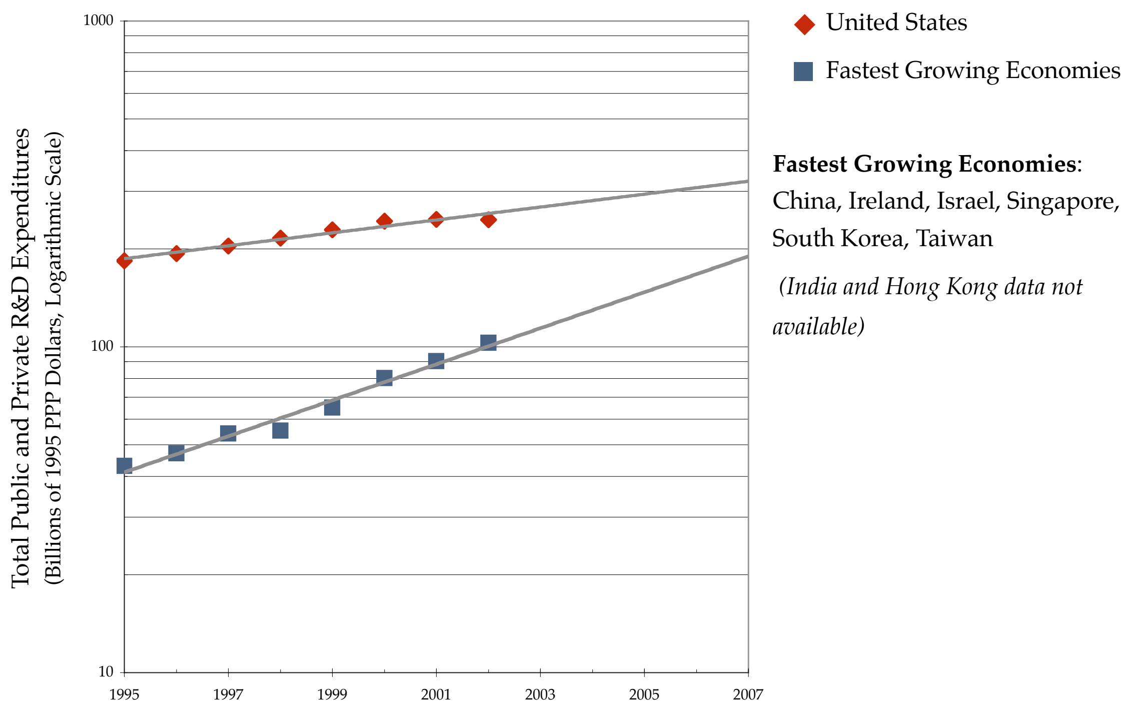
13 NSF Ind. 2004, Appdx. Table 5-48 http://www.nsf.gov/sbe/srs/seind04/append/c5/at05-48.xls

R&D Investment Benchmarks

Signs of Trouble

- Collectively, the world's fastest growing economies are on track to catch up to U.S. R&D investment. From 1995 through 2001, the emerging economies of China, South Korea, and Taiwan increased their gross R&D investments by about 140 percent. During the same period the U.S. increased its investments by 34 percent.

TOTAL R&D INVESTMENTS: FASTEST GROWING ECONOMIES GAINING RAPIDLY ON U.S.



Fastest Growing Economies: China, Ireland, Israel, Singapore, South Korea, Taiwan

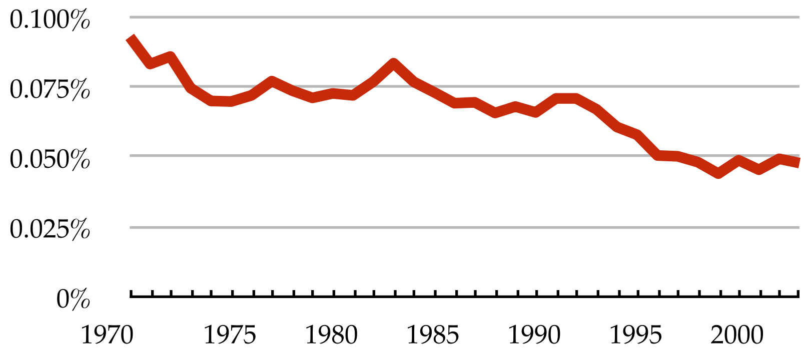
(India and Hong Kong data not available)

Source: Organisation for Economic Cooperation and Development, *Main Science and Technology Indicators*, May 2003. Compiled by the APS Office of Public Affairs

- Within the U.S., federal funding of basic research in engineering and physical sciences has experienced little to no growth over the last thirty years. In fact, as a percentage of GDP, funding for physical science research has been in a thirty year decline.

FEDERAL INVESTMENT IN PHYSICAL SCIENCES IN SIGNIFICANT DECLINE

Ratio of U.S. Federal Government Funding for Physical Sciences Research to U.S. Gross Domestic Product: 1970-2003



Source: American Association for the Advancement of Science. www.aaas.org/spp/rd/guidisc.htm
Compiled by the APS Office of Public Affairs

- Since the 1980s there has been a dynamic shift in the source of funding for R&D. U.S. private sector investment in R&D now far exceeds federal investment in R&D, providing over 68 percent of all domestic R&D. However, private funding tends to cycle with business patterns and focus on short-term results. Of these private funds, 71 percent of these private funds were for development, not basic research.[14]

- Between 1995 and 2002, China doubled the percentage of its GDP invested in R&D, from 0.6 to 1.2 percent. Also, China intends to increase the proportion of science spending devoted to basic research by more than 200 percent, to about 20 percent of its science budget, in the next 10 years.[15]

- From 1995 to 2002, Japanese businesses increased their R&D spending from 2.12 percent to 2.32 percent of GDP, and European businesses increased their R&D spending from 1.15 percent to 1.17 percent of GDP. U.S. businesses, however, actually decreased their level of spending, from more than 2 percent to 1.87 percent of GDP.[16]

14 NSF Ind. 2004, Fig. O-3 http://www.nsf.gov/sbe/srs/seind04/c0/fig00-03.htm and Lieberman White Paper, May 2004, p. 15 and http://lieberman.senate.gov/newsroom/whitepapers/Offshoring.pdf and PCAST Report, Oct. 2002 http://www.ostp.gov/PCAST/FINAL%20R&D%20REPORT%20WITH%20LETTERS.pdf

15 "OECD Countries Spend More on Research and Development, Face New Challenges." OECD, 2004. http://www.oecd.org/document/2/0,2340,en_2649_201185_34100162_1_1_1_1,00.html, and Jia, Hepeng. "Funding Boost for Basic Science in China." *SciDevNet*, 2005, http://www.scidev.net/News/index.cfm?fuseaction=readnews&itemid=1941&language=1

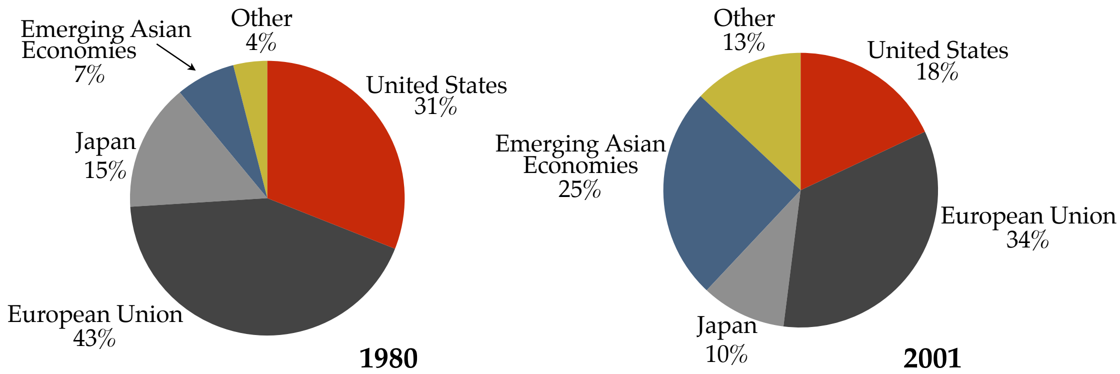
16 "OECD Countries Spend More on Research and Development, Face New Challenges." OECD, 2004. http://www.oecd.org/document/2/0,2340,en_2649_201185_34100162_1_1_1_1,00.html

High-tech Economy Benchmarks

Signs of Trouble

- The U.S. share of worldwide high-tech exports has been in a 20-year decline. From 1980 until 2001 the U.S. share fell from 31 percent to 18 percent. At the same time, the global share for China, South Korea, and other emerging Asian countries increased from just 7 percent to 25 percent.

HIGH-TECH INDUSTRY EXPORTS: U.S. LOSING WORLD SHARE



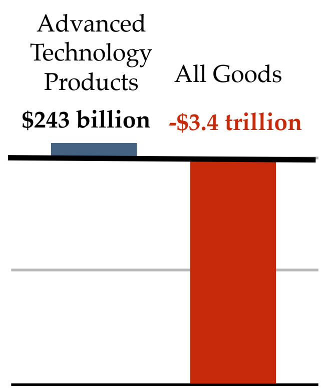
Emerging Asian Economies: China, South Korea, Taiwan, Singapore, Hong Kong, India

Source: National Science Foundation, *Science and Engineering Indicators 2004*, Appendix Table 6-1
Compiled by the Association of American Universities

- During the 1990s, the U.S. maintained a trade surplus for high-tech products even as the trade balance for other goods plummeted. But since 2001, even the trade balance for high-tech has fallen into deficit.

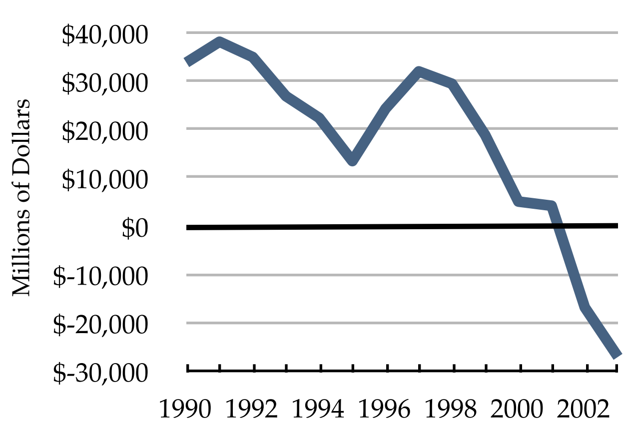
HIGH-TECH HAS DELIVERED FOR THE U.S. ECONOMY …

Cumulative U.S. Trade Balance, 1990-2003



…BUT WILL IT CONTINUE?

U.S. Trade Balance for High-Tech Products, 1990-2003

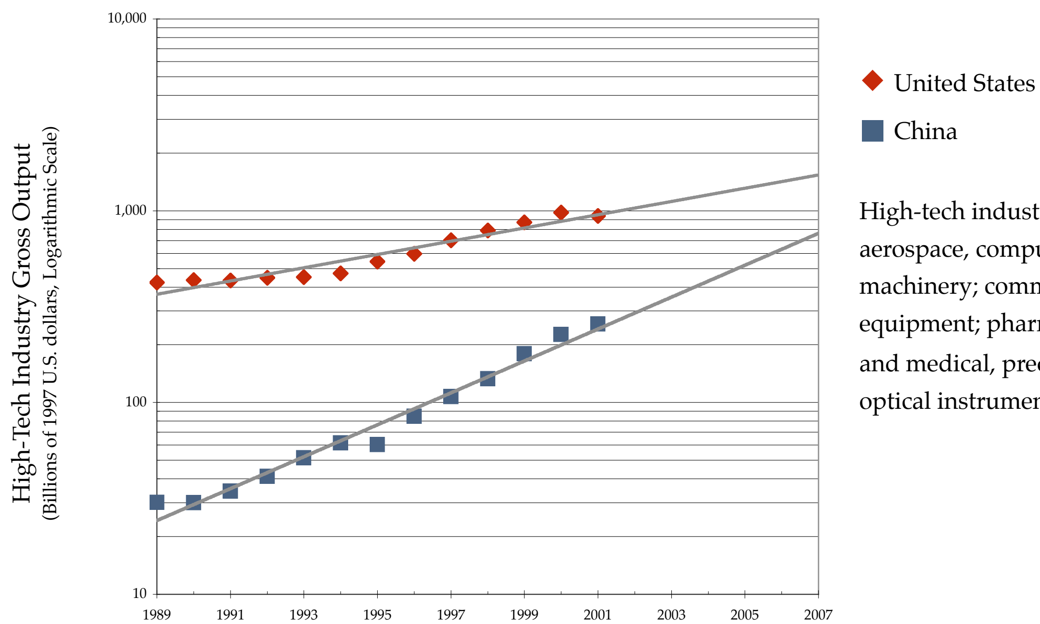


Source: U.S. Census Bureau Foreign Trade Statistics, *U.S. International Trade in Goods and Services.*
Compiled by the APS Office of Public Affairs.

- China now rivals the U.S. as a destination for foreign capital and in 2003 was the largest recipient of foreign direct investment (FDI) in the world with $53.5 billion flowing into the country.[17] Investment in U.S. businesses, meanwhile, dropped from $314 billion in 2000 to $30 billion in 2003 and $91 billion through the first three quarters of 2004.[18]

- Even while the U.S. high-tech industry grew rapidly throughout the 1990s, the high-tech industry in many Asian countries grew even faster. For example, from 1989 to 2001, U.S. high-tech output doubled, growing from $423 billion to $940 billion, but China's high-tech output shot up more than 8-fold, from $30 billion to $257 billion.

HIGH-TECH INDUSTRY OUTPUT: CHINA RAPIDLY GAINING ON U.S.



High-tech industry includes aerospace, computers and office machinery; communications equipment; pharmaceuticals ; and medical, precision and optical instruments.

Source: National Science Foundation, *Science and Engineering Indicators 2004*, Appendix Table 6-1.
Compiled by the APS Office of Public Affairs

17 Lieberman White Paper, May 2004, p.18 http://lieberman.senate.gov/newsroom/whitepapers/Offshoring.pdf

18 U.S. Department of Commerce, Bureau of Economic Analysis http://www.bea.doc.gov/bea/di/fdi21web.htm

Sector Benchmarks

Signs of Trouble

NANOTECHNOLOGY

- Asian countries are investing significantly in nanotechnology, and may have already surpassed the U.S. in this promising area of research. For example, *Small Times* reported last year: "Japan's nanotechnology budget for fiscal 2004 rose 3.1 percent to $875 million, according to Japan's Council for Science and Technology Policy. Meanwhile, the two main government ministries responsible for about 90 percent of the country's nanotechnology research programs are both seeing their budgets increased."[19]

- China has also been investing heavily in nanotechnology and already leads the U.S. in some key areas. For example: "Chinese scientists at Beijing's Tsinghua University announced that they have significantly increased the rate at which carbon nanotubes can be produced. The scientists say they have developed a new approach that produces carbon nanotubes 15 kilograms per hour, 60 times faster than the speed at which U.S. scientists had been producing them."[20] In recent surveys, China ranked third, after the U.S. and Japan, in worldwide nanotechnology patents and publications.[21]

INFORMATION TECHNOLOGY

- As the President's Council of Advisors for Science and Technology (PCAST) said in January, 2004: "In the face of global competition, U.S. information technology manufacturing has declined significantly since the 1970's, with an acceleration of the decline over the past five years."[22]

- As PCAST also noted, "Because of its overwhelming population compared to other Asian competitors, China's rise as a high tech manufacturer has caused increasing concerns. China is a large emerging market and its industrial and economic policies associated with expanding this sector are likely to continue indefinitely."[23]

- The U. S. ranks 13th out of 15 highly developed countries in household broadband penetration.[24]

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19 "Japan Boosts Nanotechnology Budget and Industrial Cooperation," *Small Times,* 15 Apr. 2004 http://www.smalltimes.com/document_display.cfm?document_id=7735

20 "China, Emboldened by Breakthroughs, Sets Out to Become Nanotech Power," *Small Times*, 17 Dec. 2001 http://www.smalltimes.com/print_doc.cfm?doc_id=2736

21 "Status of Nanotech Industry in China." *Asia Pacific Nanotech Weekly*. Vol. 2, article #24. June 23, 2004. http://www.nanoworld.jp/apnw/articles/2-24.php

22 PCAST report, Jan. 2004, pg. 6, http://www.ostp.gov/PCAST/FINALPCASTITManuf%20ReportPackage.pdf.

23 PCAST report, Jan. 2004, pg. 8 http://www.ostp.gov/PCAST/FINALPCASTITManuf%20ReportPackage.pdf

24 ITU Strategy and Policy Unit Newlog, 15 Sept. 2004 http://www.itu.int/osg/spu/newslog/categories/indicatorsAndStatistics/2004/09/15.html

ENERGY

- In the mid-1990s, the U.S. significantly scaled back its Fusion Energy Science Program, essentially ceding scientific dominance in fusion research to Europe and Japan. After these cutbacks, Europe's fusion program grew to 2.5 times the size of the US fusion program and Japan's program grew to about 1.5 times the size of the US program.[25]

- "Current expansion and growth prospects for nuclear power are centered in Asia. Twenty of the last 29 reactors to be connected to national grids are in the Far East and South Asia. And, of the 31 units under construction worldwide, 18 are located in India, Japan, South Korea, China, and Taiwan."[26] Meanwhile, most US utilities long ago dropped plans to build more nuclear reactors. In fact, no new nuclear power plants have been ordered since 1978.[27]

AEROSPACE

- From 1998 through 2003, the balance of trade in aircraft — for years one of the strongest U.S. export sectors — fell from $39 billion to $24 billion, a loss of $15 billion, reflecting increased sales of foreign-made commercial aircraft to U.S. carriers.[28]

BIOTECHNOLOGY

- China is making rapid progress in biotechnology. "The production value of the biotechnology industry throughout the country was 200 million yuan ($24 million U.S.) in 1986. In 2000, the figure reached 20 billion yuan ($2.4 billion U.S.). The output value of China's pharmaceutical industry was 200 billion yuan last year, with an annual growth rate of 20 percent in each of the previous five years."[29]

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25 Office of Fusion Energy Sciences, Aug. 1996, pp. 1 & 7 http://www.ofes.fusion.doe.gov/FusionDocuments/StrategicPlan.pdf

26 Security, Innovation, and Human Capital in the Global Interest, Speech by Dr. Shirley Ann Jackson, Ph.D., President, Rensselaer Polytechnic Institute, Center for Strategic and International Studies, June 17, 2004.

27 "Work halted on last NPPs under construction in the US", WISE News Communique, December 19, 1994. :http://www.antenna.nl/wise/index.html?http://www.antenna.nl/wise/424/4196.html

28 World Trade Atlas, based on U.S. Department of Commerce data

29 "Biotechnology could have bright future in Chinese market, experts" in *China View*, 7 July 2004. http://news.xinhuanet.com/english/2004-07/20/content_1620375.htm

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Kallender, Paul. "Japan Boosts Nanotechnology Budget and Industrial Cooperation". *Small Times*. 15 Apr 2004. http://www.smalltimes.com/document_display.cfm?document_id=7735

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"OECD Countries Spend More on Research and Development, Face New Challenges." Organisation for Economic Co-operation and Development. 23 Dec 2004. http://www.oecd.org/document/2/0,2340,en_2649_201185_34100162_1_1_1_1,00.html

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"Work Halted on Last NPPs Under Construction in US". Wise News Communiqué. 19 Dec 2004. http://www.antenna.nł/wise/index.html?http://www.antenna.nł/wise/424/4196.html

"Not only do our economy and quality of life depend critically on a vibrant R&D enterprise, but so too do our national and homeland security."

-- Hart-Rudman Commission on National Security, 2001

"It's a creeping crisis, and it's not something the American psyche responds to well. It's not a Sputnik shot, it's not a tsunami…"

-- Craig Barrett, Chairman, Intel Corporation

Task Force on the Future of American Innovation

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Benchmarks of our Innovation Future Made Possible Through …

Association of American Universities 1900

acm

ACS

AeA Advancing the Business of Technology

Agilent Technologies

AMS American Mathematical Society

APS

ASTRA Alliance for Science & Technology Research in America

Battelle The Business of Innovation

BR Business Roundtable

CompTIA

Council on Competitiveness

Computing Research Association CRA

CSPP Computer Systems Policy Project

hp invent

IBM

intel

Microsoft

MRS

NAM National Association of Manufacturers

NASULGC National Association of State Universities and Land-Grant Colleges

Northrop Grumman Defining the Future

The Science Coalition

SIA Semiconductor Industry Association

SURA

Texas Instruments

TIA Advancing Global Communications