



CHINA'S TECHNOLOGY SECTOR

*A Report Prepared by the Federal Research Division,
Library of Congress
under an Interagency Agreement with the
Director of Defense Research and Engineering,
Office of the Secretary of Defense*

September 2008

Author: Peggy S. Christoff

Project Manager: Malinda K. Goodrich

**Federal Research Division
Library of Congress
Washington, D.C. 20540-4840**

Tel: 202-707-3900

Fax: 202-707-3920

E-Mail: frds@loc.gov

Homepage: <http://www.loc.gov/rr/frd/>

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE SEP 2008		2. REPORT TYPE		3. DATES COVERED 00-00-2008 to 00-00-2008	
4. TITLE AND SUBTITLE China's Technology Sector				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Federal Research Division, Library of Congress, Washington, DC, 20540-4840				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 92	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

PREFACE

This study provides a general assessment of major science and technology (S&T) developments in the People's Republic of China (PRC) between 2000 and 2007. It is organized into eight sections: key findings, introduction, an overview of China's political system, an overview of China's S&T policy, the research and development (R&D) establishment, key S&T sectors, China's international role, and a conclusion.

In August 2007, the Organisation for Economic Co-operation and Development (OECD) published a detailed account of Chinese innovation policies during the years 1995 through 2005, using national census data and the *China Statistical Yearbook for Science and Technology*.¹ The United States National Intelligence Council, United States National Science Foundation, Office of Naval Research, U.S.–China Economic and Security Review Commission, and RAND Corporation have reported on various aspects of Chinese S&T during the same period. The author gathered information from these sources, as well as from news reports; the China National Knowledge Infrastructure (CNKI) database; Open Source Center (OSC) reports and translations; hearings of the United States Congress; scholarly presentations at the Brookings Institution and the Carnegie Endowment for International Peace; postings on C–Pol, an international listserv dedicated to Chinese politics; and the Web sites of organizations engaged in research on China, such as the National Bureau of Statistics of China and the National Bureau of Asian Research.

Because the Chinese government blocks access to data on controversial topics—particularly those related to nuclear energy, pollution, and the environment—this analysis of Chinese S&T is necessarily incomplete. In early 2009, the Chinese Academy of Sciences and Elsevier science publishers will cosponsor a special issue of the *International Journal of Technology Management*, entitled “China's New Innovation Oriented Strategy,” assessing China's 2006–2020 Medium and Long Range S&T Plan (MLP). This special issue will bring together analyses from S&T specialists around the world and bring into sharper focus the various ways China is meeting the objectives laid out in the MLP.

For the purposes of this study, S&T refers to processes, products, and services that may be created by R&D. R&D refers to the discovery of knowledge about processes, products, or

¹ Organisation for Economic Co-operation and Development (OECD), “China: A Synthesis Report” (report, OECD Reviews of Innovation Policy, OECD and the Ministry of Science and Technology, Beijing, China, August 2007), 21.

services, and the subsequent application of that knowledge to create new processes, products, or services. Innovation refers to “the purposeful combination of market and nonmarket mechanisms to optimize the production, deployment and use of new knowledge for sustainable growth, through institutionalized processes in the public and private sectors.”²

² OECD, “China: A Synthesis Report,” 21.

TABLE OF CONTENTS

PREFACE	i
KEY FINDINGS	1
INTRODUCTION	7
OVERVIEW OF CHINA'S POLITICAL SYSTEM	9
The National People's Congress and the Presidency	10
Premier of the State Council	10
National Party Congress	11
OVERVIEW OF CHINA'S S&T POLICY	12
Economic Investment	12
Social Investment	13
Political Investment	19
CHINA'S R&D ESTABLISHMENT	21
History of Chinese R&D Programs	21
<i>R&D Performers</i>	22
<i>863 Program</i>	23
<i>973 Program</i>	24
<i>Knowledge Innovation Program</i>	24
<i>Torch Program</i>	25
<i>Zhongguancun Technology Park</i>	25
<i>National Program 2006–2020 for the Development of Science and Technology</i> <i>in the Medium and Long Term</i>	26
R&D Governance	28
S&T Benchmarks	30
<i>Funding of Chinese R&D</i>	31
<i>Scientific Personnel</i>	33
<i>Patent Applications and Scientific Publications</i>	33
CHINA'S TECHNOLOGY SECTORS	35
Cutting-Edge R&D	35
<i>Nanotechnology</i>	35
<i>Biotechnology</i>	37
Energy and the Environment	39
China's Space Program	42
Advances in Military Technology	46
<i>Military Aviation</i>	49
<i>Missile Technology</i>	49
<i>Shipbuilding</i>	51
<i>Defense Electronics</i>	52

Telecommunications	53
Regional Trends in Information Technology.....	54
<i>Shanghai</i>	55
<i>Beijing</i>	55
<i>Guangzhou</i>	56
<i>Xi'an</i>	56
Semiconductors.....	58
CHINA'S INTERNATIONAL ROLE	59
Technology Transfer	60
Academic Exchanges	61
CONCLUSION.....	65
APPENDIX A.....	67
APPENDIX B	69
APPENDIX C	75
APPENDIX D.....	77
BIBLIOGRAPHY	83
TABLES	
Table 1. Programs Established to Strengthen China's Human Resources Base in S&T	14
Table 2. Factors Slowing Development of China's Human Resources.....	17
Table 3. Chinese Ministries Involved in R&D	30
Table 4. Percentage of Patents Granted to Domestic and Foreign Firms in China by Type of Activity, 1997 and 2000	34
Table 5. CNKI Nanotechnology Articles, 2000–2007.....	36
Table 6. CNKI Biotechnology Articles, 2007	38
Table 7. Regional Differences in China's IT Industry.....	58
Table 8. Dates Countries Became Members of Selected International Organizations	60
Table 9. Chinese Knowledge Transfer from International Exchange.....	63
FIGURES	
Figure 1. Regional GDP Per Capita and Regional Shares of Total R&D Expenditures	32
Figure 2. Timeline of China's Space Program.....	43
Figure 3: Estimated Funding of China's Military R&D and S&T (US\$ billion), 2003–2005	47

KEY FINDINGS

Chinese Governmental Initiatives

- Within this decade, Chinese spending on S&T has grown faster than the Chinese economy as a whole. Between 1995 and 2005, gross domestic product (GDP) in China increased by 10 percent annually, while R&D spending increased by nearly 19 percent annually.³ Analysts expect China's spending on education, which was 3 percent of the country's (GDP) in 2000, to reach 4 percent by 2020.
- China established its first high-technology park, Zhongguancun, in Beijing in 2001 and has continued to create new parks, now totaling 53. Affiliates of international corporations have transformed these parks into centers for export-oriented manufacturing. The parks were modeled after Silicon Valley to provide innovative clusters for the development of high technology. However, several barriers have impeded innovation, which has led the parks to become hubs for exporting manufactured goods.⁴
- China has successfully funded and built up government R&D centers for S&T development, but the state-owned enterprises (SOEs) with R&D centers are concentrated in a few major locations rather than dispersed widely throughout China.
- The state prefers to support research projects that either enhance China's international reputation in certain fields, such as nanotechnology, or increase China's global market share of manufactured consumer goods. As a result, China's S&T community has not harnessed technologies to solve its domestic economic, environmental, and social problems.
- The Chinese government is overly ambitious in setting expectations for the level of R&D its scientists can possibly perform. As a result, many analysts believe that Chinese scientists reverse engineer Western technologies and violate intellectual property rights (IPR). In addition, the Chinese government, unaware of the limitations of its own R&D organizations, will advocate the development of technologies that may enhance its reputation internationally (such as advancing the space program) but know nothing about how to solve fundamental problems with the way R&D is structured.

³ OECD, "China: A Synthesis Report," 9, 23.

⁴ Cong Cao, "Zhongguancun and China's High-tech Parks in Transition," *Asian Survey* 44, no. 5 (September–October 2004): 653.

- According to S&T policy expert Denis Fred Simon, the PRC's main obstacle in technology innovation is its lack of a culture of creativity.
- In 2007 only two of the 10 newly appointed members of the Politburo had scientific backgrounds, both in engineering.
- Of the 25 percent of the Chinese government's gross domestic expenditure (GDE) allocated for R&D, 6 percent funds basic research, and 70 percent funds experimental development.
- China has developed one of the most advanced telecommunications systems in the world.

Foreign Investments

- China attracts the third largest amount of foreign direct investment (FDI) in the world, after the United States and the United Kingdom (UK). More than half of the total FDI comes from Taiwan, followed by South Korea, Japan, and the United States. FDI flows into China, totaling US\$60 billion per annum, are capital intensive and focus on manufacturing.
- According to an internationally recognized expert on nanotechnology, Richard P. Appelbaum, China will advance in nanotechnology only with high levels of international collaboration.
- Foreign-owned companies conduct 40 percent of China's total R&D and hold 63 percent of the total number of patents through the World Intellectual Property Organization (WIPO) for inventions in China.
- In 2003 foreign-invested enterprises (FIEs) represented 85.4 percent of the total volume of China's high-technology exports. In 2003 FIEs exported 93 percent of Chinese computers and 96 percent of Chinese mobile communications.

National Security

- To demonstrate its technological prowess, China conducted an antisatellite (ASAT) weapons test on January 11, 2007. Within the past year, China has embarked on a

program of developing coorbital ASAT interceptors using microsatellites and nanosatellites.⁵

- Israel and Russia supply China with military equipment. For example, under a coproduction agreement, Russia supplied technical expertise for China to build the F–11 fighter; Israel was pivotal in China's work to build the J–10 fighter.
- In 1999 a Select Committee appointed by the U.S. Congress reported to the House of Representatives in the *Final Report of the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China* that China's Ministry of State Security had engaged in stealing high-technology secrets from the United States.
- The defense electronics industry, with its solid human resource base, no longer needs to directly import Western technology.
- Much of the technical information that the United States needs to track Chinese information technology (IT) is available in Chinese in open sources.
- Beijing University, Tsinghua University, East China University of Science and Technology, and Northwest Polytechnic University are responsible for the majority of China's R&D in the military sector, and, through cooperative international programs, they successfully transfer technology from foreign countries into the defense industry.
- According to a Rand study, the talent pool of scientists and engineers in the missile technology and military aviation sectors is diminishing, as R&D opportunities offered in foreign academic institutions draw experts in the field. However, because Chinese researchers consider work in the missile industry to be prestigious, the human resource base in missile manufacturing remains more stable than in the aviation sector.
- Although the China State Shipbuilding Corporation (CSSC) and the China Shipbuilding Industry Corporation (CSIC) are SOEs, reporting directly to the State Council, new and expanding interactions between R&D institutes and academic organizations within China have had a positive effect on R&D and design capabilities in the shipbuilding field. However, the shipbuilding industry continues to suffer from a lack of experienced scientific research, administrative, and management personnel.

⁵ Ashley J. Tellis, "Punching the U.S. Military's 'Soft Ribs': China's Antisatellite Weapon Test in Strategic Perspective," Policy Brief 51, Carnegie Endowment for International Peace, Washington, DC, June 2007.

Social Investment

- One obstacle to the success of China's innovation programs is the refusal of Chinese program administrators to allow project recipients to work independently or to develop technologies on their own.
- China's best and brightest scientists, tired of inappropriate intervention in their research and inadequate support for their programs, go outside of the system to live and work in other countries or, at the very least, seek employment at firms within China that do not engage in R&D requiring unencumbered scientific inquiry.
- It will take at least until 2020 before China's education system improves to the extent that it can support R&D.
- In absolute terms, undergraduate degrees in science have fallen in recent years, affecting China's ability to achieve the R&D goals outlined in the MLP.⁶
- A study conducted by the U.S. global business consulting firm McKinsey and Company concluded that a mere 10 percent of Chinese graduates, across a range of technical and professional disciplines, has sufficient training to work in foreign-based companies located in China.⁷
- Chinese universities have not adequately prepared graduates to enter the workforce, and therefore China is severely limited in its ability to develop a professional workforce in S&T.
- Unevenly developed and out-of-date higher education in China, the migration outside China of talented and specialized workers, concentration of talent in China's big cities at the expense of rural areas, the lack of marketing, management, and technical training programs, and the foreign dominance of local businesses thwart China's development of its indigenous human resources.
- One of the Chinese government's most pressing problems is planning for the future burden of social support of the Chinese population. The percentage of Chinese people of

⁶ OECD, "China: A Synthesis Report," 27.

⁷ Adam Segal, "The Civilian High-Technology Economy: Where is it Heading?" (statement at conference on Chinese Military Modernization and Export Control Regimes, U.S.–China Economic and Security Review Commission, Washington, DC, March 16, 2006), 6, <http://www.uscc.gov/>; and Howard French, "China Luring Foreign Scholars to Make Its Universities Great," *New York Times*, October 28, 2005.

working age will peak in by 2012 at 72 percent and then fall steadily to just 60 percent by 2050.⁸

- The *Financial Times* notes that the new, younger appointees to the Politburo have varied backgrounds, including the study of law, philosophy, and humanities.⁹ It seems that in China today, an education in science and engineering is not necessarily a political asset.

⁸ United States National Science Foundation, "Asia's Rising Science and Technology Strength: Comparative Indicators for Asia, the European Union, and the United States" (special report no. NSF 07-319, Arlington, Virginia, August 2007), 1, 2, 8.

⁹ Richard McGregor, "Diverse Careers of Inner Circle," *Financial Times* (London), October 22, 2007.

INTRODUCTION

In the early 1980s, under the Four Modernizations Program, China established government agencies responsible for promoting S&T. However, R&D funding did not increase substantially until the twenty-first century. International criticism of the Chinese government's massacre of students in Tiananmen Square in 1989 derailed China's progress in developing S&T exchanges. However, in 2001 China joined the World Trade Organization (WTO), signaling its desire to become a responsible stakeholder in the global economy. Following the selection of President Hu Jintao and Premier Wen Jiabao in 2002, the Chinese government established programs to encourage indigenously produced technology, as well as to promote foreign investment. After Premier Wen Jiabao announced a new 15-year S&T plan in 2006, which followed China's entry into the WTO in 2001, China began to participate in large-scale R&D in many S&T fields.

The Chinese government is the primary source of R&D funding in China, not only for government agencies, but also for universities and quasi-business entities called state-owned enterprises (SOEs).¹⁰ China's three major R&D performers are business enterprises, higher education, and research institutes. Twenty-five percent of China's medium and large business enterprises have R&D laboratories (5,545 out of 22,276); 43 percent of China's major universities and colleges conduct R&D (678 out of 1,552); and all 4,169 government research institutes have an R&D component.¹¹ Government R&D funding has proceeded according to Premier Wen Jiabao's 15-year S&T plan, the National Program 2006–2020 for the Development of Science and Technology in the Medium and Long Term (MLP).¹² The MLP aims to strengthen basic and strategic research, identifying energy and water resources for environmental protection, IT and production technologies for the market economy, and oceanography and space and aviation technology as primary areas for development. The Ministry of Science and Technology (MOST) and the National Natural Science Foundation of China (NSFC) administer government funding for these and other technologies through several programs, including 863, Spark, Torch, and 973. In addition, to expand and increase the quality of research performed by

¹⁰ OECD, "China: A Synthesis Report," 18.

¹¹ OECD, "China: A Synthesis Report," 30.

¹² The Chinese title is *Guojia zhong changqi kexue he jishu fazhan guihua gangyao 2006–2020*. See Sylvia Schwaag Serger and Magnus Breidne, "China's Fifteen Year Plan for Science and Technology: An Assessment," *Asia Policy*, no. 4 (July 2007): 145, http://nbr.org/publications/asia_policy/AP4/AP4%20Serger_Breidne%20RN.pdf.

universities and SOEs, the Chinese state provides financial initiatives for private-sector participation in R&D.

To date, these initiatives have produced modest results. A number of innate weaknesses continue to hinder China's S&T development. Most significant are China's hierarchical and repressive political structure and nationalistic ideology; its enormous landmass and geographic disparities; its lack of an innovative entrepreneurial infrastructure and a well-educated and adequately compensated human resource base; and its failure to develop sustainable solutions to its domestic issues in areas such as agriculture and the environment. Although high-technology parks intended to facilitate R&D have grown in number, the parks have evolved into holding operations for the export of goods and services. Furthermore, the human resources needed to support R&D have been slow to develop. Because funds and resources have to be redirected in order to manage serious pollution and related environmental problems, the development of a comprehensive and geographically far-reaching S&T domestic strategy is placed on the back burner.¹³ Instead of creating a domestic S&T infrastructure to address these issues, the Chinese government pursues a "leapfrog strategy," in which it bases its high-technology development on basic research already conducted elsewhere in the world. To do so, China encourages the acquisition of foreign expertise and base technologies, sometimes by illegal methods.¹⁴

Moreover, the state prefers to support research projects that either enhance China's international reputation in certain fields, such as nanotechnology, or increase China's global market share of manufactured consumer goods. As a result, China's S&T community has not harnessed technologies to solve its domestic economic, environmental, and social problems. For example, Chinese scientists have done little to develop sustainable agriculture, an S&T field that could benefit the 94 percent of the country's geographic area that is rural and the 45 percent of China's labor force that is rural; moreover, agriculture contributes 55 percent of the nation's GDP.¹⁵

¹³ Cong Cao, Richard P. Suttmeier, and Denis Fred Simon, "China's 15-Year Science and Technology Plan," *Physics Today* 59, no. 12 (December 2006): 39, <http://www.physicstoday.org/>.

¹⁴ Cong Cao, "New Key Players in the Global System of Science, Technology, and Education" (preliminary report, Levin Graduate Institute of International Relations and Commerce, State University of New York, 2007), 1, 2, 3, 5 (cited with the consent of the author).

¹⁵ U.S. Federal News Service, "China's 'New Village' Strategy—Actual Progress and National Impact" (transcript of public presentation, speaker Biliang Hu and moderator Albert Keidel, Carnegie Endowment for International Peace, Washington, DC, January 31, 2008), <http://carnegieendowment.org/files/NVS.pdf>.

The Chinese government has made efforts to encourage grassroots entrepreneurship. For example, the state strengthened patent laws and, in January 2008, implemented R&D tax credits for both Chinese-owned and foreign-owned companies. However, the government has not changed its hierarchical administrative structure.¹⁶ Although three of China's largest SOEs—China Telecom, China Mobile, and China Unicom—trade publicly, the government continues to micromanage them, hiring and firing their chief executives. Furthermore, the Chinese state's control of other enterprises, such as the telecommunications giant Huawei, has dampened market pressures that might encourage such companies to innovate, reducing their ability to compete in the long term.

The Chinese government is overly ambitious in setting expectations for the level of R&D its scientists can possibly perform. As a result, many analysts believe that Chinese scientists reverse engineer Western technologies and violate intellectual property rights (IPR). In addition, the Chinese government, unaware of the limitations of its own R&D organizations, will advocate the development of technologies that may enhance its reputation internationally (such as advancing the space program) but know nothing about how to solve fundamental problems with the way R&D is structured.¹⁷

OVERVIEW OF CHINA'S POLITICAL SYSTEM

Although China's total land mass is roughly comparable to that of the United States, consisting of 3,705,805 square miles, its population of 1,313,549,000 is about five times larger than the population of the United States. China's political divisions include the communist mainland; democratic Taiwan; and two special administrative regions—Hong Kong, regained in 1997, and Macao, regained in 1999. The communist mainland, known as the People's Republic of China (PRC), governs the latter two territories under the principle of “one country, two systems,” meaning that although Hong Kong and Macao are considered to be part of China, they

¹⁶ Serger and Bredne, “China's Fifteen Year Plan,” 157.

¹⁷ According to Serger and Bredne (p. 160), “Efforts to increase China's innovative strength have been driven by a strong belief that by dedicating enough money to science and technology, China will generate innovative and competitive companies. Simply put, the government is investing in world-class scientists, perfectly equipped labs, and science parks (sometimes cynically referred to as ‘dollars, divas, and dazzling buildings’) but is also neglecting the ‘intangibles’—such as favorable institutional and framework conditions that significantly influence a country's innovative capacity.”

maintain distinct political systems.¹⁸ Taiwan maintains its own political and economic systems and is not under PRC control. The findings in this study do not include Taiwan or Macao.

The PRC consists of 22 provinces and four centrally administered municipalities: Beijing, Chongqing, Shanghai, and Tianjin. Shanghai is the most populous (12,887,000), followed by the capital, Beijing (10,839,000).¹⁹

The National People's Congress and the Presidency

The National People's Congress (NPC), a unicameral body that selects leading government officials and amends the Chinese constitution, is China's highest organ of state power. Not to be confused with the Chinese Communist Party's (CCP) National Party Congress, which meets every five years, the NPC meets annually. The NPC comprises approximately 3,000 delegates, elected to five-year terms, by municipal and provincial congresses and units of the armed forces. At the tenth NPC in 2003, Hu Jintao succeeded Jiang Zemin as the president of China, the highest official in the country. One year later, the CCP's National Party Congress elected Hu to serve a five-year term as general secretary of the CCP, and in 2004 the NPC appointed Hu as chairman of the CCP Central Military Commission (CMC). Normally, the president of China assumes all three posts simultaneously, but in this case former president Jiang Zemin extended for a year his terms as general secretary of the CCP and chairman of the CMC.²⁰ In March 2008, the NPC appointed all new members to the State Council.

Premier of the State Council

The second most powerful leader in China is its premier, who also heads the State Council. The president nominates the premier, and the NPC approves the appointment. The premier, who serves no more than two successive five-year terms, nominates other members of the State Council, comprising vice premiers, the heads of ministries and commissions, the auditor general, and the secretary general. In 2003 the NPC confirmed the appointment of Wen Jiabao to serve a five-year term as premier, succeeding Zhu Rongji. Because the Ministry of

¹⁸ Arthur S. Banks, Thomas C. Muller, and William R. Overstreet, eds., *Political Handbook of the World 2007* (Washington, DC: Congressional Quarterly, 2007): 227–37.

¹⁹ Banks et al., *Political Handbook of the World 2007*, 227–37.

²⁰ Banks et al., *Political Handbook of the World 2007*, 227–37.

Science and Technology (MOST) is under the State Council, Prime Minister Wen played a major role in drafting the MLP.²¹

National Party Congress

The CCP's National Party Congress, which convenes for two weeks every five years, met for the seventeenth time on October 15, 2007. Regarding National Party Congress activities, Alice Miller, an authority on China's political system at the Hoover Institution, has described the elaborate process of issuing a national political report, including multiparty consultations, drafts, reviews, and revisions. The process reveals that the political report is a consensus document reflecting compromise and negotiation among competing leaders and party constituencies. Moreover, the report is general, allowing differing constituencies to interpret it as they see fit.²²

In November 2002, the 16th National Party Congress appointed 198 full and 158 alternate members to its Central Committee, and the Central Committee designated a nine-member Standing Committee and 15 additional Politburo members.²³ Some analysts predicted that the members of the Politburo in 2002—eight engineers and one geologist—would have enough power to keep S&T policy on an even path. However, in 2007 only two of the 10 newly appointed members of the Politburo had scientific backgrounds, both in engineering.²⁴ The *Financial Times* notes that the new, younger appointees to the Politburo have varied backgrounds, including the study of law, philosophy, and humanities.²⁵ Apparently, in the present day, a candidate educated in engineering, especially one who has advanced knowledge in

²¹ Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan."

²² Alice Lyman Miller, "The Road to the 17th Party Congress," *China Leadership Monitor*, no. 18 (Spring 2006): 5, http://media.hoover.org/documents/clm18_lm.pdf.

²³ Banks et al., *Political Handbook of the World 2007*, 227–37.

²⁴ The C-Pol listserv provided the names of the new members of the Politburo with their backgrounds in parentheses: Xi Jinping (Marxist theory and ideological education), Li Keqiang (economics), Wang Gang (philosophy), Wang Qishan (economics), Liu Yandong (political science), Li Yuanchao (mathematics), Wang Yang (engineering), Zhang Gaoli (economics), Xu Caihou (engineering), and Bo Xilai (journalism). See communication on the C-Pol listserv, October 22, 2007. Established in 1999 as an owner-moderated listserv, Chinapol is an online e-mail forum designed by Richard Baum, professor of Chinese studies at UCLA. Its purpose is to facilitate rapid, informal communication among specialists around the world in contemporary Chinese politics, economics, and related fields. Based in 23 countries, its subscribers are scholars, journalists, diplomats, and analysts from government, nongovernmental organizations (NGOs), and think tanks. Presently, Chinapol is the primary information network linking the growing global community of China watchers. In 2003 a small group of voracious critics of the Chinese communist regime split off from Chinapol and formed Pangolinpol; however, Chinapol remains the dominant listserv for Chinese politics. Professor Richard Gunde, in UCLA's Center for Chinese Studies, has archived all Chinapol communication.

²⁵ McGregor, "Diverse Careers of Inner Circle."

areas that are sensitive to China vis-à-vis its international reputation (the use of coal, the construction of nuclear power plants, the levels of pollution from automobile emissions, or China's space program) do not seem to occupy high-level positions (for example, in the Politburo).²⁶

Three years before the 2007 party congress, the NPC approved two constitutional amendments: one proclaimed that private enterprise is an important component of the socialist economy, and the other supported the principle of the rule of law. Although both constitutional amendments aim to support China's economy, the CCP still does not permit a free market of ideas, causing China great difficulty in developing the vibrant entrepreneurial class needed to advance levels of R&D.²⁷

OVERVIEW OF CHINA'S S&T POLICY

Beginning in 1978 with the Four Modernizations Program, Chinese leaders attempted to implement S&T policy, initiating a dramatic paradigm shift away from Mao Zedong's isolationism and toward Deng Xiaoping's open-door policy. In the beginning, the Four Modernizations Program segregated economic development into four groups: agriculture, industry, science and technology, and national defense.²⁸ Today's National People's Congress continues to allocate resources to China's economy, social structure, and political system, according special attention to these four groups.

Economic Investment

Steel, coal, chemicals, and agricultural industries are the backbone of China's economy. However, the highly centralized Chinese government is slow to promote diffused, specialized producer and R&D networks to support industry. In China's current financial system, only SOEs qualify to receive funding from the central bank. As a result, Chinese investors—many of whom

²⁶ Careers in engineering are politically sensitive because of the potential for espionage. See U.S. Federal News Service, "Former Boeing Engineer Charged with Economic Espionage in Theft of Space Shuttle Secrets for China," February 11, 2008.

²⁷ Jerry Stryker, communication on the C-Pol listserv, October 23, 2007.

²⁸ Richard Baum, ed., *China's Four Modernizations: The New Technological Revolution* (Boulder, Colorado: Westview Press, 1980); and Serger and Breidne, "China's Fifteen Year Plan," 138.

have amassed fortunes under the present system—are reluctant to provide venture capital to small- and medium-sized enterprises (SMEs).

China's most significant economic investment in S&T policy is its establishment of high-technology parks. Termed *jigongmao* (*ji* is shorthand for *technological development*, *gong* refers to *industry*, and *mao* means *commerce*), high-tech parks provide incentives for Chinese firms to secure a position in the global marketplace. One positive result of globalization has been that China pays greater attention to IPR and adheres to technical standards and tries to promulgate its own for product development through *jigongmao*.²⁹ However, because the Chinese government and local firms do not coordinate their activities, China has failed to develop stable, complementary national and subnational economies.³⁰

Social Investment

Although China engages in scientific research to enhance existing industrial products and to develop new commercial ones, the Chinese government does not deal effectively with fluctuations in the Chinese workforce. One of the government's most pressing problems is planning for the future burden of social support of the Chinese population. The percentage of Chinese people of working age will peak in 2012 at 72 percent and then fall steadily to just 60 percent by 2050.³¹

A little more than 20 years ago, China began to consult with S&T policy analysts in the West about reforming its human resources policies. As a result, China's MOST established incentives to reward outstanding performance in basic research, as well as in the areas of high technology, innovation and commercialization, technology transfer, S&T exchange, and education. See table 1 for a list of centrally directed and coordinated programs intended to strengthen China's human resource base and the section of this report on China's R&D establishment for a discussion of the most prominent of these programs.

²⁹ Cao, "Zhongguancun and China's High-tech Parks in Transition," 653, 656, 667.

³⁰ Adam Segal, *Digital Dragon: High Technology Enterprises in China* (Ithaca, New York: Cornell University Press, 2003): 8–9.

³¹ Cao, Suttmeier, and Simon, "China's 15-Year S&T Plan," 43.

Table 1. Programs Established to Strengthen China's Human Resources Base in S&T****Most prominent programs are in bold font.**

Activity	Programs
Basic Research	973 Program Yangtze River Scholars One Hundred Talents Distinguished Young Scientists
High Technology	863 Program
Innovation/Commercialization	National New Product Program
Technology Transfer	Torch Spark "Action Plan for Thriving Trade through S&T"
S&T Exchanges	National Key Laboratory Program Numerous MOST programs for sharing equipment, resources, S&T literature, R&D databases, research networks
Education	New Century Talents Training University Young Scholar Awards
Source: Organisation for Economic Co-operation and Development (OECD), "China: A Synthesis Report" (report, OECD Reviews of Innovation Policy, OECD and the Ministry of Science and Technology, Beijing, China, August 2007), 64 and 66.	

One obstacle to the success of these programs is the refusal of Chinese program administrators to allow project recipients to work independently or to develop technologies on their own. In addition, since the 1980s and until this day, the heads of the CCP's political departments, who make high-level personnel appointments in key S&T institutes, do not have scientific backgrounds.³² Furthermore, S&T programs lack a system of checks and balances to ensure consistency, objectivity, and autonomy. Supervisors of financial institutions, unable to grasp the concept of offering loans to R&D companies with no strings attached, often become overly involved in the companies' day-to-day operations.³³ China's best and brightest scientists, tired of inappropriate intervention in their research and inadequate support for their programs, go outside of the system to live and work in other countries or, at the very least, seek employment at firms within China that do not engage in R&D requiring unencumbered scientific inquiry (e.g., the basic sciences).³⁴

In addition to investing in performance-based programs to encourage R&D, China needs to invest in educating a workforce of future scientists and engineers. In 2000 China spent 3

³² Cong Cao and Richard P. Suttmeier, "China's New Scientific Elite: Distinguished Young Scientists, the Research Environment, and Hopes for Chinese Science," *China Quarterly* 168 (December 2001): 971.

³³ Segal, *Digital Dragon*, 15.

³⁴ Cong Cao, "Chinese Science and the Nobel Prize Complex," *Minerva* 42 (2004): 151–72.

percent of its GDP on education, and analysts expect that expenditure to reach 4 percent by 2020. As of 2007, it will take at least 20 years before China's education system improves to the extent that it can support R&D. Presently, the curricula and methods of teaching are out of date and do not support the fast-paced growth brought in by foreign-invested enterprises. In analyzing Chinese S&T, OECD predicts that China's education system will not become a stable social investment for at least 20 years. Since the early 1990s, China has made progress in developing human resources trained in S&T, although it still lags behind most OECD countries in the percentage of its population educated in these fields. To build an innovative economy, China must have sustained growth of its S&T human resource base.³⁵

Although at present undergraduate and postgraduate enrollment in science and engineering remain strong, between 2000 and 2006 the percentage of graduates specializing in these fields declined. In absolute terms, undergraduate degrees in science have fallen in recent years, affecting China's ability to achieve the R&D goals outlined in the MLP.³⁶ A study conducted by the U.S. global business consulting firm McKinsey and Company concluded that a mere 10 percent of Chinese graduates, across a range of technical and professional disciplines, has sufficient training to work in foreign-based companies located in China.³⁷ Taking advantage of the need for qualified scientists and engineers in China, unaccredited entrepreneurial educational institutions have begun to offer S&T certificates in lieu of formal academic degrees.³⁸

In addition to the propagation of substandard academic institutions, some members of the Chinese scientific community have been accused of academic dishonesty.³⁹ In 2006 Liu Ming, published a critique of China's academic evaluation system.⁴⁰ Because the number of a scientist's publications, particularly those listed in *Thomson's Scientific Citation Index*, determines individual promotions, Chinese scientists have succumbed to the temptation to practice deceit. In a survey conducted by a member of China's own State Council, 60 percent of graduates holding PhDs confessed that they had paid money to have their work published, while

³⁵ Cao, "New Key Players in the Global System," 6.

³⁶ OECD, "China: A Synthesis Report," 27.

³⁷ Adam Segal, "The Civilian High-Technology Economy: Where is it Heading?," 6; and French, "China Luring Foreign Scholars to Make Its Universities Great."

³⁸ David Lague, "Chinese Paradox: A Shallow Pool of Talent," *International Herald Tribune* (Paris), April 25, 2006.

³⁹ Serger and Bredine, "China's Fifteen Year Plan," 143.

⁴⁰ Serger and Bredine, 144, footnote 18.

a similar percentage admitted to having copied, claiming as their own, already published works.⁴¹

Because of better wages and working and living conditions abroad, China loses many of its highly qualified professionals to foreign countries. According to Cong Cao and Richard P. Suttmeier, “Although only about one-third of the 380,000 who went abroad between 1980 and 2000 over the past 20 years have gone back to China, those who have returned have come to play important roles in implementing the ambitious policies for scientific research and high technology development which have unfolded in the post-Mao era.”⁴² Moreover, as the country becomes an international hub, recruiters from foreign-owned companies within China successfully tap into local talent. Although Chinese and foreign firms compete to develop imported ideas and products, adapting them for Chinese consumption, these companies lack the collaborative, consensus-building culture that would permit their endeavors to flourish. The Chinese government’s hierarchical decision-making structure impedes the efforts of entrepreneurs.

Table 2 describes five factors that thwart China’s development of its indigenous human resources:

1. Unevenly developed and out-of-date higher education in China
2. The migration outside of China of talented and specialized workers
3. Concentration of talent in China’s big cities at the expense of rural areas
4. The lack of marketing, management, and technical training programs
5. Foreign dominance of local businesses⁴³

Of these factors, China’s inadequate education system and the migration of Chinese scientists to the West (commonly referred to as *brain drain*) are the most critical to R&D.

⁴¹ Paul Mooney, “Plagued by Plagiarism,” *Chronicle of Higher Education*, May 19, 2006. For a more complete discussion of corruption in China, see Minxin Pei, “Corruption Threatens China’s Future” (policy brief 55, Carnegie Endowment for International Peace, October 2007), 1–8, http://www.carnegieendowment.org/files/pb55_pei_china_corruption_final.pdf; and Cao, Suttmeier, and Simon, “China’s 15-Year S&T Plan,” 40.

⁴² Cao and Suttmeier, “China’s New Scientific Elite,” 960.

⁴³ OECD, “China: A Synthesis Report,” 27–28.

Table 2. Factors Slowing Development of China's Human Resources

Growth-Retarding Factors	Description of Status Quo	Negative Effects of Current Practices
Low-quality education (especially in universities and colleges)	Chinese institutions have high graduation rates, but the quality of education is uniformly low in both S&T and non-S&T fields at the graduate, undergraduate, and vocational technology levels. Educational institutions struggle to implement modern curricula.	Workers and employers view diplomas merely as credentials for job promotions, rather than as indicators of the level of a candidate's knowledge in a particular field of study.
Workforce's migration outside China	The pattern of permanent emigration of the workforce is changing. Over the past few years, more Chinese are returning, after a stint overseas, than in the past. However, for the most part, Chinese who emigrate remain outside of China, particularly in the United States, continuing to provide help to their relatives within China.	The U.S. government, having discovered cases of espionage by Chinese nationals, has become increasingly suspicious of Chinese activities in the United States.
Concentration of talent in China's big cities	S&T clusters fail to take advantage of local talent outside of the big cities and to foster relationships among firms, universities, and research institutes.	Local and national cultures have become increasingly separate and isolated.
Lack of worker training in specific businesses	Businesses do not build on expertise their staff has gained through experiential learning, nor do they circulate expertise throughout the organization.	Chinese workers have no loyalty to or trust in China's present business structure.
Low levels of technical expertise in workforce	Turnover of skilled technical and professional workers is high, because these workers are searching for innovation-oriented enterprises.	Highly skilled Chinese workers migrate from Chinese companies to foreign-owned companies and do not replenish China's R&D infrastructure
Absence of marketing and management skills	Because educational institutions and other government-run entities do not value these skills, other professions draw individuals with potential in these areas.	Academic and government S&T entities fail to develop the potential of their human resources.
Foreign dominance of local businesses	Foreign-owned enterprises (FOEs) use China's best and brightest workers and do not help Chinese companies develop.	Prevalence of FOEs stifles China's national development of R&D.
Source: Organisation for Economic Co-operation and Development (OECD), "China: A Synthesis Report" (report, OECD Reviews of Innovation Policy, OECD and the Ministry of Science and Technology, Beijing, China, August 2007), 27–28 (Figures 2.6, 2.7, 2.8, 2.9).		

Between 2000 and 2005, a surge of undergraduate students enrolled in colleges and universities throughout China, making it difficult for administrators to chart educational trends. The PRC has no precedent for such a surge, which could enable the Chinese government to foresee or to manage its consequences. In 2000 enrollment in higher education institutions

reached 5 million students, jumping to 15 million in 2005.⁴⁴ Analysts collecting qualitative information from students and professors indicate, however, that because of their out-of-date curricula and poor instruction, Chinese universities have not adequately prepared graduates to enter the workforce.⁴⁵ In addition, China's one-child-per-family policy has caused population declines over time, resulting in fewer young, college-aged people.⁴⁶

In addition to the increased enrollment in Chinese institutions of higher education, there has been a surge of students traveling abroad to study. Between 2000 and 2005, the number of Chinese students going overseas for their education increased by 33 percent of those that leave, with the percentage of students returning to China fluctuating between 15 percent and 33 percent. In 2000, 40,000 Chinese students went abroad, and 10,000 returned; by 2005, 120,000 were studying abroad, and 40,000 had returned.⁴⁷

Currently, Australia, European Union (EU) countries, Japan, New Zealand, and the United States are the primary hosts to Chinese students. In 2003 a record high of 90,000 Chinese students studied in the United States; 70,000 studied in EU countries; 45,000, in Japan; 15,000, in Australia; and 10,000, in New Zealand. However, in 2004 more Chinese students went to EU countries (90,000) than to either the United States (87,000) or Japan (75,000).⁴⁸ In part, this change reflects increased U.S. and Japanese government restrictions on student visas.⁴⁹ When the United States and China have disagreements over policy issues, the Chinese government may redirect students to study in Europe. However, it is certain to remain true that China regards U.S. higher education in S&T as the best in the world and, on balance, will continue to send many students to the United States.

⁴⁴ OECD, "China: A Synthesis Report," 28 (Figure 2.7).

⁴⁵ Paul Mooney, "The Long Road Ahead for Chinese Universities," *Chronicle of Higher Education*, May 19, 2006; Michael Pettis, correspondence on C-Pol listserv, May 8, 2006.

⁴⁶ United States National Science Foundation, "Asia's Rising Science and Technology Strength: Comparative Indicators for Asia, the European Union, and the United States" (special report no. NSF 07-319, Arlington, Virginia, August 2007), 1, 2, 8.

⁴⁷ OECD, "China: A Synthesis Report," 28.

⁴⁸ People's Republic of China, Ministry of Science and Technology, "S&T Statistics Data Book 2007," <http://www.most.gov.cn/eng/statistics/2004/index.htm>.

⁴⁹ United States, Government Accountability Office, "Border Security: Improvements Needed to Reduce Time Taken to Adjudicate Visas for Science Students and Scholars" (report no. GAO-04-371, Washington, DC, February 25, 2004).

Political Investment

Historian of Chinese S&T Benjamin Elman notes that, since the middle of the nineteenth century, all Chinese leaders—including imperial reformers, early Republicans, Nationalist Party cadres, and Chinese Communists—have made S&T a top priority.⁵⁰ Given this historical precedent, it is not surprising that, every 10 years since the end of the Great Proletariat Cultural Revolution in 1976, the PRC has promoted a series of slogans supporting S&T initiatives. During the revolution, Chairman Mao Zedong promoted the notion of *zili gensheng*, or *self-reliance*, justifying his policy of isolation from the outside world. Presently, the slogans employed, some of which are throwbacks to the 1960s, are: *zizhu changxin*, meaning *indigenous innovation*; *yujun yunmin*, meaning *harnessing the private sector for military use*; *quanmian xiaokang shehui*, meaning *promoting an overall well-off society*; and *liangdan yixing*, meaning *the two mega projects, nuclear weapons and the space program*.⁵¹

Nevertheless, in spite of the PRC's eagerness to engage in innovative, indigenous R&D, China's cumbersome political and economic system continues to interfere with its S&T initiatives. Although both President Hu and Premier Wen support innovative S&T policies, China's planned economy and top-heavy R&D structure thwart any significant changes to the status quo. For example, as Chinese S&T management expert Yifei Sun notes, China has yet to assess its 20-year-old S&T programs, to determine their effectiveness.⁵² The rise of nationalism in China, as a component of domestic politics, also influences S&T development. According to Adam Segal, senior fellow of China Studies at the Council on Foreign Relations in New York, the Chinese government's role in technology development has become more explicitly nationalistic.⁵³ Today, China's leadership asserts that Chinese people from all walks of life can become scientists, apparently mirroring the rhetoric of the Great Leap Forward during the 1950s, when Chairman Mao encouraged a proliferation of backyard steel factories and "barefoot doctors." In another example of proletarian rhetoric of the 1990s, Chinese leaders endorsed the creation of nongovernmental enterprises (*minying qiye*) to "unleash the potential of the scientific

⁵⁰ Benjamin A. Elman, *A Cultural History of Modern Science in China* (Cambridge, Massachusetts: Harvard University Press, 2006), 1.

⁵¹ Segal, "The Civilian High-Technology Economy," 1; and Cao, Suttmeier, and Simon, "China's 15-Year S&T Plan," 38, 40, 41.

⁵² Yifei Sun, "China's National Innovation System in Transition," *Eurasian Geography and Economics* 43, no. 6 (September 2002): 478. Sun is the editor of the new assessment to be published by Elsevier science publishers (as cited in the preface of this report).

⁵³ Segal, *Digital Dragon*, 168.

community at the grass roots level.”⁵⁴ However, the concept of *minying qiye* lost its political potency and has disappeared from present-day discourse.⁵⁵

Chinese leaders appeal to the nationalism of their citizenry, claiming that S&T advances will enable China to become a global power through the slogan “revitalizing the nation through science and education.” Moreover, China’s leaders continue to hope that China will receive a Nobel Prize. Although, according to Chinese S&T specialists Cong Cao and Richard P. Suttmeier, China has made several significant high-level S&T advances, China’s quest for the Nobel Prize reflects its leaders’ eagerness for quick and glamorous scientific and political success rather than developing levels of R&D that the Chinese infrastructure can sustain.⁵⁶

The Chinese government attempts to assure its domestic audience that international S&T will help solve China’s most daunting challenges, including poverty, pollution, and epidemics.⁵⁷ The possibility exists that if China encounters a large-scale disaster leading to massive public protests, Chinese leaders may shift the blame to the international community, feeding Chinese xenophobia. However, after the earthquake in Sichuan in the spring of 2008, the Chinese people did not engage in massive protests against the government. Nationalism is a double-edged sword. In addition, the 2008 Summer Olympic Games, China’s successful antisatellite weapons tests in 2007, and being the third country to put a human being in space in 2003, have played well domestically.

The leadership’s tremendous drive to succeed has led to gross violations of IPR. Specifically, China has involved its nationals in espionage in the United States.⁵⁸ In 1999 a Select Committee appointed by the U.S. Congress reported to the House of Representatives in the *Final Report of the Select Committee on U.S. National Security and Military/Commercial Concerns with the People’s Republic of China* that China’s Ministry of State Security had engaged in stealing high-technology secrets from the United States. In response, the U.S. government prosecuted two U.S. companies, Loral Space and Communications Corporation and

⁵⁴ Segal, *Digital Dragon*, 4, 41.

⁵⁵ Joseph Torigian, e-mail message to author, September 27, 2007. Torigian is Adam Segal’s research assistant.

⁵⁶ Cao and Suttmeier, “China’s New Scientific Elite,” 151–72.

⁵⁷ Richard P. Suttmeier, “Science and Technology: A New World In the Making?” in *Strategic Asia 2004–05*, vol. 4, *Confronting Terrorism in the Pursuit of Power*, ed. Ashley Tellis and Michael Wills (Seattle: National Bureau of Asian Research, 2004), 461, http://www.nbr.org/publications/strategic_asia/pdf/sa04_14sci-tech.pdf.

⁵⁸ United States–China Economic and Security Review Commission, “China’s Technology Development and Implications for the U.S. Defense Industrial Base,” Chap. 2 in *Report to the Congress of the United States* (Washington, DC: GPO, 2005), 93, http://www.uscc.gov/annual_report/2005/annual_report_full_05.pdf.

Hughes Electronics Corporation, for violating the Arms Export Control Act. The Chinese government continues to claim that China does not engage in any form of espionage.⁵⁹

The Chinese government attempts to neutralize extremes. It does not want the Chinese populace to become discouraged that the government will never develop indigenous industries; nor does it want the Chinese populace to believe that it has to depend on the West to learn anything. Harmonizing these contradictions, China's MLP straddles "indigenous innovation" and "learning from the outside world." The appointment of Wan Gang in 2007 as Minister of Science and Technology provides an apt example. Like many scientists and academicians, Wan is not a member of the CCP. Furthermore, in addition to pure science research, he has considerable experience in industry. In addition, as an overseas returnee who left a successful career in the United States, Wan is committed to harnessing foreign ideas to foster Chinese modernization.⁶⁰

The international S&T community considers China a responsible political stakeholder because its leaders regularly consult with outside S&T experts. However, China continues its repressive domestic policies. For example, its leaders provide high technology in support of the military sector, specifically to reinforce the objective of state surveillance and public security. One ramification is that this objective does not allow for risk-taking or tolerate the occasional failure that is inherent in innovation.⁶¹

CHINA'S R&D ESTABLISHMENT

History of Chinese R&D Programs

In the early 1980s, China's paramount leader, Deng Xiaoping, established the first national R&D program under the State Science and Technology Commission (SSTC). In 1985 the SSTC's replacement agency, MOST, established the NSFC, implementing and funding

⁵⁹ For the text of the U.S. investigation, see United States Congress, House Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China, *Final Report of the Select Committee*, 106th Cong., 1st sess., January 3, 1999, <http://www.house.gov/coxreport/>. For the Chinese government's response, see Federation of American Scientists, news release, translation of the PRC's refutation of the *Final Report of the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China*, <http://www.fas.org/sgp/news/1999/07/chinacox/index.html>.

⁶⁰ Serger and Breidne, "China's Fifteen Year Plan," 154.

⁶¹ Cao, "Zhongguancun," 650.

several performance incentive programs, including the 863, 973, Knowledge Innovation, and Torch programs.⁶²

Currently, China is in the last of four stages of a paradigm shift in R&D. The first stage began after the Cultural Revolution in 1976, when Deng Xiaoping promoted the Four Modernizations Program. The Four Modernizations emphasized the development of agriculture, industry, national defense, and S&T. Between 1978 and 1985, Deng reopened universities and created special economic zones (SEZs). In stage two, between 1985 and 1995, a larger segment of the Chinese government initiated relationships among universities, public R&D laboratories, and business enterprises. The 863 Program, launched in 1986, and the Torch Program, instituted in 1988, created cooperative exchanges among universities, public R&D labs, and business enterprises.⁶³

The third stage of the R&D paradigm shift occurred between 1995 and 2005, when China prepared to become a global player. In 2006 China began its fourth and present stage in R&D, with Premier Wen Jiabao's introduction of China's 2006–2020 Medium and Long-Range S&T Plan (MLP), a detailed 15-year S&T plan to strengthen Chinese firms internationally. In this fourth stage, R&D has become the driver for sustainable development.⁶⁴

R&D Performers

China's three major R&D performers are business enterprises, higher education, and research institutes. Twenty-five percent of China's medium and large business enterprises have R&D laboratories (5,545 out of 22,276); 43 percent of China's major universities and colleges conduct R&D (678 out of 1,552); and all 4,169 government research institutes have an R&D component. Assessments thus far indicate that higher education is the weakest link.⁶⁵ Analysts believe that, if China can upgrade its education system by 2020, a new era will begin.⁶⁶

⁶² OECD, "China: A Synthesis Report," 53–54.

⁶³ OECD, "China: A Synthesis Report," 41.

⁶⁴ OECD, "China: A Synthesis Report," 45 (Figure 3.1).

⁶⁵ See Serger and Breidne, 141 (Figure 2).

⁶⁶ OECD, "China: A Synthesis Report," 30.

863 Program

Focusing on global competitiveness, the 863 Program, named for the year and month of its inception, March 1986, sought to enhance applied research in IT, biological and advanced agricultural technology, advanced materials, advanced manufacturing and automation, and energy and the environment. In addition, the 863 Program introduced a variety of management techniques, including a peer-review system for scientific research, which is modeled on that of the United States. According to Chinese S&T policy expert Richard P. Suttmeier, Chinese leaders' perceptions of international trends, including China's interactions with multinational corporations (MNCs); the rapid growth of Chinese students and scholars studying abroad; a host of ambitious domestic reforms; and the interests of the Chinese military sector, particularly the strategic weapons community, contributed to the concept of the 863 Program.⁶⁷

Growth in the numbers of Chinese students seeking a college education stimulated the PRC to create new funding strategies for the development of its S&T sector, such as the 863 Program. In response to increased enrollments in Chinese universities, in 1990 China's State Council transferred into higher education one-quarter of the funds it had previously allocated for national public research organizations (PROs). An Oxford Analytica study applauded this strategy, noting that the growth in university and college enrollment justifies a reform of higher education. By the end of 2005, China had 23 million students in its institutions of higher learning, and, in the same year, the number of graduates reached 3.4 million. The number of higher education institutions has since exploded, from 598 in 1971 to 1,731 in 2004, while the number of higher education faculty members working full-time has expanded fourfold, from 206,000 in 1978 to 858,000 in 2004.⁶⁸ Increasing the numbers of college graduates has yielded a new class of knowledge workers, thereby strengthening a range of industry sectors. In turn, both R&D and S&T initiatives have sparked a synergy among higher education institutions, government programs, and industrial actors. Between 2001 and 2005, as part of China's 10th Five-Year Plan, the State Council increased fourfold R&D funding for the 863 Program.

⁶⁷ Richard P. Suttmeier, "China's Techno-Warriors: Another View," review of *Chinese Techno-Warriors: National Security and Strategic Competition from the Nuclear Age to the Information Age*, by Evan Feigenbaum, *China Quarterly* 179 (September 2004): 804–10.

⁶⁸ Oxford Analytica, "National Innovation Systems of India and China" (draft report to the National Intelligence Council, Washington, DC, November 24, 2006), 30.

973 Program

Building on the 863 Program, which focused on applied research in technology, in March 1997, MOST launched the 973 Program to promote basic research in the fields of IT, biotechnology, space, energy resources, automation, and lasers. The purpose of the 973 Program was to strengthen innovation and further integrate S&T into China's economic and social institutions. However, in *China Voices II*, a Chinese-language supplement of the UK-based science magazine *Nature*, U.S.-based Chinese life scientists report that, having witnessed the politics involved in China in allocating government funding, they have come to believe that MOST is more focused on ensuring its own survival than on enhancing R&D throughout the many Chinese institutions it is supposed to serve.⁶⁹ Between 2001 and 2005, as part of China's 10th Five-Year Plan, the State Council began to provide funding for the 973 Program.⁷⁰

Knowledge Innovation Program

Through the Knowledge Innovation Program (KIP), the Chinese Academy of Sciences (CAS) oversees basic research and cutting-edge R&D in the areas of agriculture, health, energy, and the environment. Building on the 863 and 973 programs, the State Council created the KIP in 1998 for the purpose of introducing structural reforms in the R&D sector, including the CAS; strengthening the business sector's involvement in R&D; and establishing program evaluation techniques—including financially oriented metrics and performance drivers.⁷¹ Originally the KIP aimed to renew and reinvent the CAS, China's oldest and most prestigious research institution, by authorizing the establishment of 30 internationally recognized research institutes. By 1999 the CAS sought to alleviate the cumulative effects of overstaffing and inefficiency by downsizing CAS-generated PROs in the fields of natural sciences and high technology, developing Chinese businesses instead.⁷² Because of the KIP, the number of research institutes under the CAS involved in S&T declined from 40 to 29; and the number of government employees in the institutes decreased by an average of 47 percent.⁷³ It is expected that the impact

⁶⁹ Cao, Suttmeier, and Simon, "China's 15-Year S&T Plan," 42.

⁷⁰ OECD, "China: A Synthesis Report," 54.

⁷¹ Richard P. Suttmeier, Cong Cao, and Denis Fred Simon, "Knowledge Innovation and the Chinese Academy of Sciences," *Science* 312, no. 5770 (April 7, 2006): 58–59.

⁷² Cao, Suttmeier, and Simon, "Knowledge Innovation," 58–59.

⁷³ Cao, Suttmeier, and Simon, "Knowledge Innovation," 58–59.

of these declines will be evaluated as part of an early 2009 special issue of the *International Journal of Technology Management*, which will present analyses of the MLP by S&T specialists from around the world.

The KIP's attempt to strengthen China's business sector has not been completely successful. One problem the KIP has encountered is that, once a Chinese business enterprise has achieved success, institutes within the CAS seek to reclaim it. The most dramatic example of this occurred in 2000, when the CAS Institute for Computing Technology initiated a reverse takeover of Legend, a business enterprise that had achieved a substantial profit margin.⁷⁴

Torch Program

The Torch Program, instituted in 1988 as part of a dramatic structural reform of China's S&T system, broadened the sources of S&T funding for nongovernmental enterprises and promoted the creation of high-technology zones. The Torch Program encourages entrepreneurs to leave government-based R&D institutes and start their own companies. Currently, S&T administrators provide Torch funds to the most promising start-up enterprises, from their inception to their introduction of products into the commercial marketplace. By 2003 China had established 53 S&T industrial parks (STIPs) under the Torch Program. However, many have become distribution, processing, or trading centers for foreign technology companies. See Appendix A for a listing of China's 53 high-technology parks.⁷⁵

Zhongguancun Technology Park

MOST used California's Silicon Valley as a model for its first STIP, Zhongguancun.⁷⁶ After the park's opening in 2001, Chinese students and scholars returning from abroad established more than 2,100 new Chinese firms at the new STIP. According to research by Cong Cao, "In 2003 total income from technological development, industry, and commerce reaped by Zhongguancun's enterprises hit RMB 284 billion (US\$34.3 billion), up 18.1 percent from 2002."⁷⁷ In addition, several MNCs—including Ericsson, IBM, Intel, Microsoft, Mitsubishi, and

⁷⁴ Suttmeier, Cao, and Simon, "Knowledge Innovation," 58–59.

⁷⁵ Cao, "Zhongguancun," 648.

⁷⁶ Cao, "Zhongguancun," 648.

⁷⁷ Cao, "Zhongguancun," 654–55.

Motorola—opened R&D centers in or near Zhongguancun. The non-Chinese R&D centers, now exceeding 750, are cooperative ventures partnering with universities and research institutes.⁷⁸

National Program 2006–2020 for the Development of Science and Technology in the Medium and Long Term

On January 9, 2006, at the 4th National Conference on Science and Technology, Premier Wen Jiabao summarized the goals of China's 15-year science and technology plan, the MLP, as follows:

1. To develop technologies related to energy and water resources for environmental protection
2. To master core technologies in information technology and production technologies
3. To accelerate the pace of development in oceanography and in space and aviation technology
4. To strengthen both basic and strategic research⁷⁹

A translation of an outline of the MLP is attached to this report in Appendix B.

The MLP outlines China's 10 national S&T priorities: energy, water and minerals, the environment, urban development, agriculture, manufacturing, transportation, information and service industries, population and health, and public safety. The MLP also identifies 22 specific technologies that are to be targeted, including:

- Deep-sea operation technology
- Design technology for animal and plant varieties
- Distributed energy supply technology
- Extreme manufacturing technology
- Fast neutron stacking technology
- Genetic manipulation and protein engineering technologies
- High performance raw and processed material technology
- High-temperature superconductor technology

⁷⁸ Kathleen A. Walsh, "China's High-Technology Development" (testimony before the U.S.–China Economic and Security Review Commission hearings on China's High-Technology Development, Palo Alto, California, April 21, 2005), 4, http://www.uscc.gov/hearings/2005hearings/written_testimonies/05_21_22wrts/walsh_kathleen_wrts.pdf.

⁷⁹ Serger and Bredne, "China's Fifteen Year Plan," 145.

- Hydrogen energy and fuel cell technology
- Industrial biological technology
- Intelligent material and structure technology
- Intelligent perception technology
- Intelligent service robots
- Magnetically confined nuclear fusion
- Natural gas hydrate technology
- Self-organized network technology
- Stem cell research
- Technologies for pharmaceutical molecules
- Technology for predicting the life cycles of major products and major facilities
- Technology for the rapid survey of multiple parameters of the bottom of the ocean
- Technology for three-dimensional monitoring of the ocean environment
- Virtual reality technology⁸⁰

China's 18 goals for basic research as outlined in the MLP include:

- Biological basis of human health and diseases
- Brain science and cognitive science
- Complex systems and the formation of catastrophes and their prediction and control
- Creation of new materials and transforming chemical processes
- Global changes and regional responses
- Global system processes and their effect on resources, the environment, and disasters
- Growth and reproduction research
- Improvement in agricultural heredity and scientific problems in the sustainable development of agriculture
- Innovations in scientific experimentation and observation methods, technology, and equipment
- Key scientific problems in the sustainable development of energy resources
- Major aerospace physics problems
- Nanotechnology

⁸⁰ Outline of the Medium and Long Range National Plan for Scientific and Technical Development (2006–2020).

- New principles and new methods in the design and preparation of materials
- Protein research
- Quantum regulation and control research
- Scientific basis for supporting the development of IT
- The effect of human activity on global systems
- The scientific basis for manufacturing under extreme environmental conditions⁸¹

Cao, Suttmeier, and Simon describe the MLP in terms of strategic research areas, key areas, frontier technologies, engineering megaprojects, and science megaprojects. See Appendix C for their breakdown of the MLP.

Although the 15-year plan has been in effect for only two years, the CAS, in conjunction with the U.S.-based *International Journal of Technology Management*, is in the process of evaluating the results of the MLP in the areas of Chinese technology transfer, foreign R&D operations, national innovation system reforms, human resource development, and high-technology industries. The *International Journal of Technology Management* will publish this report in early 2009.⁸²

R&D Governance

China's State Council oversees all bodies responsible for governing R&D. Under its purview, a steering committee articulates policy, delegating to the National Development and Reform Commission the responsibility for coordinating various ministries involved in R&D. The Ministry of Science and Technology (MOST) is the main ministry involved in implementing the State Council's S&T policy objectives. MOST's major functions are to

1. formulate strategies, priority areas, policies, laws and regulations;
2. build a national innovation system;
3. conduct research on major S&T issues promoting China's economic and social development;
4. reform the current S&T system;
5. form policies to enhance interactions among basic research, high-technology development, and industrialization;

⁸¹ Outline of the Medium and Long Range National Plan for Scientific and Technical Development (2006–2020).

⁸² Yifei Sun, e-mail correspondence with author, July 24, 2007.

6. design R&D programs that industries will want to support financially, such as science parks and incubators;
7. increase investments in S&T;
8. identify talented scientists and place them in appropriate positions; and
9. promote international S&T exchanges (See table 9 for a listing of Chinese international S&T exchanges by country.)⁸³

As described in table 3, China's national interests, ranging from basic science to applied military research, involve commerce, finance, education, and human resource development institutions including the Commission of Science, Technology, and Industry for National Defense, the State Intellectual Property Office, the Ministry of Commerce, the Ministry of Finance, and others.

⁸³ OECD, "China: A Synthesis Report," 54.

Table 3. Chinese Ministries Involved in R&D

Primary Ministry/Institution	Partnering Ministry/Institution	Priorities
Commission of Science, Technology, and Industry for National Defense (COSTIND)		Defense-related R&D and military applications of commercial technology
State Intellectual Property Office		Policymaking on patents and other IPR issues
Ministry of Commerce (MOC)	Ministry of Finance (MOF)	Tax relief for exports of high-technology products and preferential treatment of foreign direct investment (FDI) in high-technology areas
Ministry of Finance (MOF)	Ministry of Science and Technology (MOST)	Funds for innovation in small, technology-based firms
Ministry of Science and Technology (MOST)		Incubators and science parks, measures for supporting research and the application technologies and popularizing science.
Ministry of Education (MOE)	Ministry of Science and Technology (MOST)	University-related R&D, science parks, and human resources development
Ministry of Personnel (MOP)	Chinese Academy of Sciences (CAS)	Overseas Chinese scholars and postdoctoral program management
Chinese Academy of Sciences (CAS)		Research and administration of the Knowledge Innovation Program (KIP)
National Natural Science Foundation of China (NSFC)		Basic research funding
Chinese Academy of Engineering (CAE)		S&T policy advice
National Development and Reform Commission (NDRC)		Productivity Promotion Centers and innovation in SMEs
Source: Sylvia Schwaag Serger and Magnus Breidne, "China's Fifteen Year Plan for Science and Technology: An Assessment," <i>Asia Policy</i> , no. 4 (July 2007): 155.		

S&T Benchmarks

Benchmarking data are useful for predicting future domestic and global challenges. Four benchmarks commonly are used to compare S&T across national boundaries:

1. Amount of R&D spending
2. Number of scientific personnel
3. Number of patent applications
4. Scientific publication activity

Funding of Chinese R&D

The Chinese government is the primary source of R&D funding, not only for government agencies, but also for universities and quasi-business SOEs. Although individual Chinese organizations and foreign private entities increasingly fund R&D, their contribution is minor. When set against China's rapidly growing economy, the rise in China's R&D-to-GDP ratio is remarkable. In 2003 the R&D-to-GDP ratio was 1.13 percent, and in 2004 it was 1.23 percent.⁸⁴ Furthermore, China's R&D-to-GDP ratio has more than doubled in a decade, reaching 1.34 percent in 2005, compared to 0.6 percent in 1995, although it is still far behind most countries in Asia.⁸⁵ By 2005 China became the sixth largest spender on R&D in the world.⁸⁶

Of the 25 percent of the Chinese government's gross domestic expenditure (GDE) allocated for R&D, 6 percent funds basic research, and 70 percent funds experimental development. A large portion of R&D resources goes to building hardware to support R&D or investing in large-scale renewal of equipment and facilities. China spends more on development than on research. As a result, the business sector lags in developing patentable inventions.⁸⁷

Because R&D is concentrated at present in eastern and coastal China, especially in the cities of Beijing and Shanghai, an increase in R&D funding will not produce a systemic process of innovation throughout China. Beijing and Shanghai regulate foreign investment for R&D facilities and grant residency permits within their respective municipalities independent of the central government.⁸⁸ Subnational governments control tax revenues, and, as of result of the wide geographical distances, knowledge producers and potential users within China do not interact.⁸⁹ See figure 1 for a map of regional GDP per capital and regional shares of total R&D expenditures in China.

⁸⁴ United States National Science Foundation, "Science and Engineering Statistics," <http://www.nsf.gov/statistics/>.

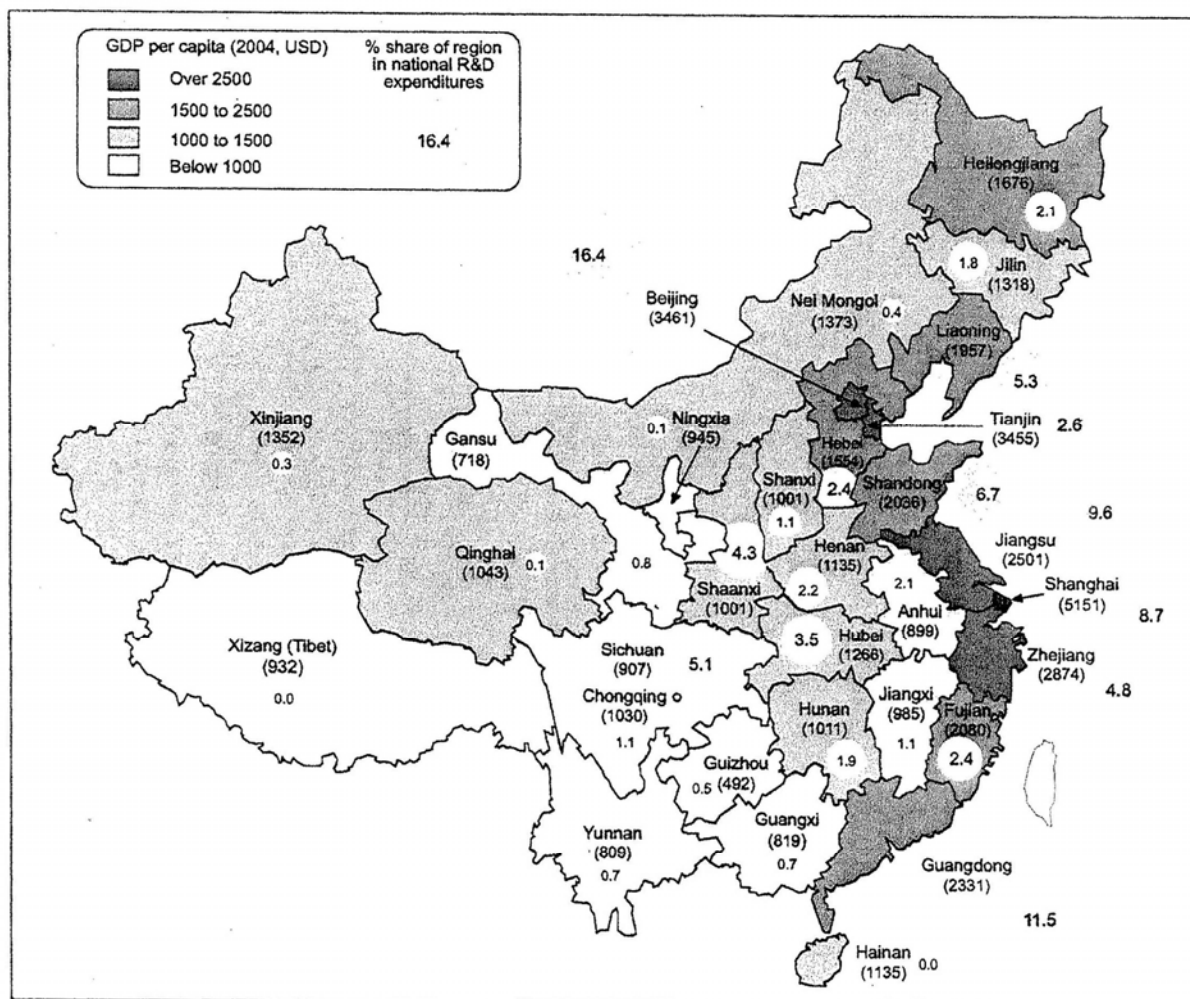
⁸⁵ Segal, "The Civilian High-Technology Economy," 2.

⁸⁶ Serger and Breidne, "China's Fifteen Year Plan," 146; and United States National Science Foundation, "Asia's Rising Science and Technology Strength," 15, 17.

⁸⁷ OECD, "China: A Synthesis Report," 24 (Figure 2.3).

⁸⁸ Banks et al., *Political Handbook of the World 2007*, 227–37.

⁸⁹ OECD, "China: A Synthesis Report," 25 (Figure 2.4, reproduced here).



Source: National Bureau of Statistics (2005), *Chinese Statistical Yearbook 2005*; MOST.

Figure 1. Regional GDP Per Capita and Regional Shares of Total R&D Expenditures

In addition, the Chinese government provides tax incentives and tax relief, for both Chinese- and foreign-owned domestic SMEs to encourage R&D. For example, the government has eased visa requirements for locals and foreign nationals and provides tax relief for equipment imports. To encourage indigenous industries to become competitive in the global marketplace, the Chinese government initiated new tax incentives in January 2008 for local industries that adhere to strict licensing and technical standards, as well as granting tax rebates to foreign investors.⁹⁰ In introducing China's Enterprise Income Tax Law in January 2008, Xue Lan, from the School of Public Policy and Management at Tsinghua University in Beijing, noted a

⁹⁰ Serger and Bredne, "China's Fifteen Year Plan," 149.

provision for Chinese and foreign-owned businesses to deduct 150 percent of their R&D expenses.⁹¹

Scientific Personnel

Although the quality of China's science and engineering education lags far behind that of France, Germany, Japan, Russia, and the United States, as of 2006, China had more engineering graduates than India and the United States combined. The United States had 137,437 engineers, India had 112,000, and China had 351,537. Rather than searching for comparable numbers of scientists across countries, it is important to understand that the scientific personnel that China lacks are in the area of program management. Research is not planned well. According to Suttmeier, Cao, and Simon, program managers are needed to develop evaluation standards and processes for scientific research.⁹²

Patent Applications and Scientific Publications

An analysis of patenting activities recorded in China's State Intellectual Property Office classifies China's innovation capabilities in three areas:

1. inventing new technologies;
2. devising new ways to use existing technology; and
3. developing new designs for existing technology.⁹³

Compared to foreign firms in China, Chinese firms are stronger in finding new ways to use existing technology but significantly weaker in creating new ones. According to S&T policy expert Denis Fred Simon, the PRC's main obstacle in technology innovation is its lack of a culture of creativity.⁹⁴ As indicated in table 4, China has maintained a steady growth in its development of new designs for existing technology, compared with foreign firms, which have

⁹¹ Lan Xue, "Recent Developments of Chinese Government Policies on High-Tech Industries and Innovation" (presentation at public program on China's Increasingly High Technology Trade: Facts, Policies, and Implications, sponsored by the Brookings Institution and the Carnegie Endowment for International Peace, Washington, DC, September 26, 2007), <http://www.carnegieendowment.org/events/index.cfm?fa=eventDetail&id=1064&&prog=zgp&proj=zdr1,zgpf>; and Serger and Breidne, "China's Fifteen Year Plan," 158.

⁹² Tellis, "Punching the U.S. Military's 'Soft Ribs'," 59.

⁹³ United States National Science Foundation, "Asia's Rising S&T Strength," 30.

⁹⁴ Denis Fred Simon, "The Technology Transfer Issue in Sino-U.S. Relations, 1981–2006: Some Reflections, Thoughts, and Perspectives" (paper presented at the meeting of the U.S.–China Forum on Science and Technology (S&T Policy), Beijing, China, October 16–17, 2006).

reduced this type of innovative activity by 50 percent over the last 10 years.⁹⁵ These statistics, reported by OECD, assume that China's State Intellectual Property Office has a transparent process in granting patents, which may not be the case. However, it is difficult to know whether China would under- or over-report the numbers of patents it has granted.

Table 4. Percentage of Patents Granted to Domestic and Foreign Firms in China by Type of Activity, 1997 and 2000

	Chinese Firms	Foreign Firms
1997		
Inventing new technologies	3	41
Using existing technologies	57	5
Developing new designs for existing technologies	40	54
2000		
Inventing new technologies	11	74
Using existing technologies	48	3
Developing new designs for existing technologies	41	23
Source: OECD, "China: A Synthesis Report," 13, 32 (Figures 1.10 and 2.15).		

As indicated in table 4, invention patents granted by the Chinese State Intellectual Property Office to Chinese firms increased from 3 percent in 1997 to 11 percent in 2000. By contrast, patents for foreign firms in China increased from 41 percent to 74 percent within the same period. However, although China has doubled its number of patent applications through the World Intellectual Property Organization, Serger and Breidne state that large foreign firms held roughly two-thirds of all invention patents granted in China in 2004.⁹⁶ Furthermore, in comparing international scientific publications, the United States Office of Naval Research found that, in basic research, China ranked fifth in 2005 in its number of international science publications, behind the United States, United Kingdom, Germany, and Japan.⁹⁷

Chinese policymakers publicly state a desire to reduce Chinese dependence on foreign technology by 30 percent by 2020.⁹⁸ Historically, China has outperformed foreign firms in adapting new technologies, so it is not surprising that, in the present day, China quickly adapts technologies that the United States invents. This facility to adapt is problematic for relations

⁹⁵ OECD, "China: A Synthesis Report," 13, 32 (Figures 1.10 and 2.15).

⁹⁶ OECD, "China: A Synthesis Report," 42 (Figure 2.21); and Serger and Breidne, "China's Fifteen Year Plan," 147.

⁹⁷ For an analysis of scientific literature in China, see Ronald N. Kostoff et al., *The Structure and Infrastructure of Chinese Science and Technology* (Arlington, Virginia: Office of Naval Research, 2006).

⁹⁸ OECD, "China: A Synthesis Report," 38; Serger and Breidne, "China's Fifteen Year Plan," 147; and Richard P. Suttmeier, "The Next Great Leap Forward," review of *The Writing on the Wall: China and the West in the 21st Century*, by Will Hutton, *New Scientist* (February 10, 2007), 46.

between the United States and China. American policymakers point out that China's ability to assimilate U.S. inventions leads China to disregard intellectual property rights and gives rise to U.S. security concerns regarding technology transfer of state-of-the-art technologies.⁹⁹

CHINA'S TECHNOLOGY SECTORS

Cutting-Edge R&D

Nanotechnology

As Chinese planners and policymakers strive to strike a balance between state-led and market-led economic development, they have identified nanotechnology as an area where China has the potential to become a world leader. The government funds R&D especially to strengthen China's economic base for both the manufacturing and medical industries in this field. Between 2000 and 2007, the China National Knowledge Infrastructure (CNKI) database indexed more than 200 scientific and technical articles on various aspects of nanotechnology.¹⁰⁰ According to the database, 26 of China's 31 administrative regions (i.e., municipalities and provinces) are involved in nanotechnology R&D. Not surprisingly, the geographic locations senior scholar at the Council on Foreign Relations Adam Segal studied in the IT industry—Beijing, Guangzhou, Shanghai, and Xi'an—also figure prominently in the area of nanotechnology. Four provinces—Hubei, Henan, Jiangsu, and Zhejiang—also have significant R&D in the field.

The discipline most affected by advances in nanotechnology is materials science. China has conducted broad-based and comprehensive national and regional surveys and reports on numerous nanotechnology applications in materials science. In addition to materials science, nanotechnology has particular application in the fields of medicine and the environment. Table 5 provides a listing, by administrative region, of R&D topics in the CNKI database.

Analysts often cite China as a world leader in nanotechnology, including technologies of interest to the military sector such as energetic materials, electronic materials, infrared detection, and metallurgy. However, according to an internationally recognized expert on nanotechnology,

⁹⁹ Stephen Roach, "America's Inflated Asset Prices Must Fall," *Financial Times* January 8, 2008.

¹⁰⁰ The databases of the CNKI include China Academic Journals, China Core Newspapers, China Dissertations, China Conference Proceedings, and China Academic Journals bibliography. Tsinghua University, the leading S&T center in China, produces the CNKI. The China Academic Journals database alone contains over 9.5 million full-text articles from over 5,000 serials on all academic subjects.

Richard P. Appelbaum, China will advance in that field only with high levels of international collaboration.¹⁰¹ The U.S. National Science Foundation has developed a program, Partnership for International Research and Education (PIRE), to support collaborative research internationally in a wide range of technologies, including nanotechnology. China is a participant in PIRE, as are Brazil, Germany, Japan, and the Netherlands.¹⁰²

Table 5. CNKI Nanotechnology Articles, 2000–2007

Administrative Regions	Topics
Anhui	Molecular surgery; high-performance fibers; metal ceramic tool materials
Beijing	Environmental protection; biosensors and bio chips; medicine and pharmaceuticals; antioxidative corn activity peptides; water pollution; biomedical engineering; organic metallic molecular nanosystems; vacuum electron beams and evaporation systems; chemicals and risk analysis; physical mechanics; DNA research in military medicine; molecular crowns; advances in silver halide; life sciences in the People's Liberation Army (PLA); coating materials; petrochemical industry; polymer modifications
Gansu	Purification of automobile exhaust; modification of agricultural plastic
Guangdong	Textiles; thermoelectric materials; crude oil pollutants; light medicine powder; environmental science; applications to the rubber industry; biomedical sciences in the military sector; paper coatings; cloning techniques
Guangxi	Medicine (electronic communication engineering); environmental protection
Guizhou	Semiconductors; nano-biotic projects in the PLA
Hebei	Water pollution; metallurgical industries; medical science and engineering; agriculture and environmental protection; applications in electric power
Heilongjiang	Environmental protection
Henan	Papermaking; animal husbandry; water pollution; nano-materials; disease diagnosis
Hubei	Wastewater treatment; biomedicine; refractory and high-temperature ceramics; materials synthesis; applications to national defense industries; pharmaceuticals; polymer materials
Hunan	Biology (engineering and agriculture); anticancer therapies; nano-wood science; tumor treatments
Jiangsu	Food science; textiles; water pollution; environmental protection; tumor therapy; dermatology; water ecology; therapy for hepatocellular carcinoma; surfactants (chemical engineering); self-assembly; plastics
Jiangxi	Medicine; die and mould manufacturing; welding; molecular science and advanced materials
Jilin	Therapeutics and malignant tumors; forensic DNA
Liaoning	Information technology (IT); water pollution
Nei Menggu	Medicine and pharmaceuticals
Shaanxi	Welding technology; air-filter technology; materials for environmental protection; textiles; biomedicine; analog inner loops and digital outer-loop micro-fabrication technology; wastewater treatment
Shandong	Pharmacology; chemicals; vehicle manufacturing; pharmaceuticals; rubber composites; polymer modification

¹⁰¹ Richard P. Appelbaum, "CNS Voices: Rich Appelbaum on Nanotechnology Research in China," interview by Center for Nanotechnology in Society, University of California, Santa Barbara, September 14, 2006, <http://www.cns.ucsb.edu/>.

¹⁰² United States National Science Foundation, "Asia's Rising Science and Technology Strength," 2.

Table 5. CNKI Nanotechnology Articles, 2000–2007

Administrative Regions	Topics
Shanghai	Treatment of tumors; cell biology; sports technology; ophthalmology; water pollution; optimization of silver/graphite contact materials; exterior architectural coatings; nano-herbs; electrical contact materials; occupational medicine; micro-motors; organic coating, rubber, and plastics; metrology
Shanxi	Textiles; gene therapy; polyurethane industry
Sichuan	Electronics (life sciences); material sciences (general); pharmaceuticals; magnetic materials; materials in the petroleum industry
Tianjin	Precision engineering; biomedicine; medicine and pharmaceuticals; agent composites; military medical equipment
Yunnan	Application to precious metals
Zhejiang	Food science; biosensor and bio-detection devices; animal husbandry; textiles (worsted fabric)
Source: China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (analysis of 262 articles).	

An investigation of Chinese R&D on nanotechnology provides rich information on the management and structure of Chinese S&T in general. For example, several articles address the reasons China needs to devote substantial resources to this field and how scientists and engineers should conduct research. The R&D management structure in Beijing also has established incentive programs for nanotechnology. Two Chinese centers, the Shanghai Nanotechnology Promotion Center and the Tianjin Nanotechnology Industrialization Base of China, focus on commercial applications.¹⁰³

Biotechnology

R&D in nanotechnology has influenced the field of biotechnology. Examining articles published in the CNKI database during 2007, the researcher identified more than 50 biotechnology R&D articles. As indicated in table 6, the dominant geographic regions engaging in biotechnology R&D are Beijing, Hubei, Liaoning, Shandong (near Beijing), and Sichuan. Ten administrative regions did not report research on biotechnology.¹⁰⁴

State-of-the-art biotechnology focuses on R&D in agriculture and, as with nanotechnology, on the environment, with a third concentration in medical technology. According to the U.S. National Institutes of Health (NIH), China conducts extensive basic research on the human genome, which includes neuroscience and brain mapping of epilepsy.

¹⁰³ Appelbaum, "CNS Voices: Rich Appelbaum on Nanotechnology Research in China."

¹⁰⁴ A survey of R&D articles between 2000 and 2007 yielded more than double the number of biotechnology articles compared to those in nanotechnology (i.e., 658 compared to 233).

One example of international cooperative research with China supported by the Fogarty International Center and other NIH institutes, is a project called “Brain Disorders in the Developing World.” In addition, China is a major participant in the World Health Organization’s Global Campaign against Epilepsy.¹⁰⁵

Articles published in 2007 reinforce the notion that, in the R&D equation, China is stronger in “D” than in “R”. The CNKI listing of biotechnology articles also reveals increased attention to higher education and curriculum development in that field.

Table 6. CNKI Biotechnology Articles, 2007

Administrative Regions	Topics
Anhui	Prospects of hydrogen production; environmental protection; reforms of the teaching curricula
Beijing	Quality improvement in forage grasses; pattern genetics; purity identification of rice seed; magnetic particles; biomass materials; agricultural applications of basic research; monoclonal antibody vaccines (i.e., stem cell research); survey of agricultural biotechnology developments; metabolic engineering
Guangdong	Nano-biotechnology in the chemical industry
Guangxi	Green chemistry
Hebei	L-Tryptophan; lettuce breeding
Heilongjiang	Nanometers in general surgery; patent law and rights protection
Henan	D-sodium ascorbate in wastewater
Hubei	Technical expertise in agriculture; regional survey of agricultural biotechnology; enterprise patent strategies; sustainable forests in minority nationality regions; cultivating professionalism in chemical engineering
Hunan	Regional survey of agricultural biotechnology; cultivating innovation in teaching and research
Jiangsu	Curriculum development (enhancing student professionalism); curriculum reform in analytical chemistry and inorganic chemistry
Jiangxi	Conversion of lignocellulosic into ethanol
Jilin	Fruit and vegetable plants
Liaoning	Curriculum development (bilingual teaching); brewers’ spent grain; degenerative intervertebral disc lesions (stem cell research); high salinity organic wastewater treatment
Shaanxi	Curriculum development (creative education)
Shandong	Curriculum development (teaching reform); pinellia terrlate (genetic engineering); food biotechnology; wastewater treatment; intellectual property rights
Shanghai	Enzyme application in agriculture; salvia miltiorrhiza bunge
Sichuan	Countermeasures in military medicine; impact of biotech crops on rural environments; microbial strain improvement and high throughput screening (pharmaceuticals); pathways of ginkgolides (traditional Chinese medicine)
Tianjin	Brassica oleracea var. botrytis (genetic plant breeding); analysis of US biotechnology
Yunnan	Purity identification of rice seed
Zhejiang	Purity identification of rice seed; bromeliads (plant science)
Source: China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (analysis of 62 articles).	

¹⁰⁵Yuan Liu, Chief of the Office of International Activities and Director of Computational Neuroscience and the Neuroinformatics Program, NIH, e-mail message to author, September 10, 2007.

Energy and the Environment

As a mega economy, China's energy needs are vast and depend on both oil and coal. China is the largest producer and consumer of coal in the world. Coal makes up 69 percent of China's total primary energy consumption. China has the third largest coal reserves in the world, behind the United States and Russia. In oil, China is the second largest consumer in the world behind the United States and the third largest net importer after the United States and Japan. The U.S. Department of Energy's Energy Information Administration (EIA), an organization that supplies the U.S. government with official energy statistics worldwide, estimates that China's increase in oil demand represented 38 percent of the world's total increase in demand in 2006.¹⁰⁶

At Harvard University's Energy Technology Innovation Project, U.S. researchers have compiled statistical comparisons highlighting the tremendous challenges China faces in increasing the efficiency of its current energy system. Furthermore, the World Resources Institute confirms that China has not yet produced technologies to increase efficiency in coal usage and continues to focus on R&D in energy and pollution.¹⁰⁷

For 2007 the CNKI database indexed approximately 200 articles on energy technology. The subjects of these studies included energy conservation, electric power systems, petrochemicals, thermal power, solar energy and other renewable or alternative energy resources, heat conservation (especially in buildings), energy storage, and energy consumption.¹⁰⁸ At this point, studies do not assess specific successes or failures in R&D in the energy field.

China faces tremendous challenges in developing technologies that increase efficiency in coal usage. The Huanang Group in Beijing has established a consortium of power and coal interests to build the first Chinese integrated gasification combined cycle (IGCC) technology demonstration plant by 2010.¹⁰⁹ To date, the dominant coal technology remains coal

¹⁰⁶ United States, Department of Energy, Energy Information Administration, "China: Background," n.d. <http://www.eia.doe.gov/emeu/cabs/China/Background.html>.

¹⁰⁷ Deborah Seligsohn, director of the China Program, Climate Energy and Pollution Program, World Resources Institute, e-mail correspondence with author, February 15, 2008. See also People's Republic of China, "China's Scientific and Technological Actions on Climate Change" (joint report of the Ministry of Science and Technology and others, China, June 2007), <http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File199.pdf>.

¹⁰⁸ China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp.

¹⁰⁹ Peter Fairley, "Part I: China's Coal Future," *Technology Review*, January 4, 2007, <http://www.technologyreview.com/Energy/17963/>; and Peter Fairley, "Part II: China's Coal Future," *Technology Review*, January 5, 2007, <http://www.technologyreview.com/Energy/17964/>.

pulverization. R&D topics in CNKI focus on coal-fired power plants, sieve systems, mining technology, and safety studies.¹¹⁰

To curb its use of coal, China is building a series of nuclear power plants. Currently, four plants serve the east and southeast regions and, between 2005 and 2020, China will build between 20 and 32 more. In Dalian in the northeast, a consortium of Chinese SOEs—the Guangdong Nuclear Power Group, the China Power Investment Corporation, and the Dalian Municipal Construction Investment Corporation—currently is constructing China's most recent nuclear power plant, which is designed by Westinghouse and conforms to U.S. quality control standards.¹¹¹

In developing nuclear technology, China continues to rely on foreign technology instead of investing over the long term in training a new generation of Chinese nuclear engineers. Nonetheless, Chinese scientists are speeding up R&D in fourth-generation pebble-bed, modular, high-temperature, gas-cooled reactors (HTGR). Besides Japan and South Africa, China is the only country to operate an HTGR experiment, which, if its performance can be validated, will help meet China's increasing demand for electricity.¹¹²

In the environmental sphere, China has taken only small steps to reduce energy consumption, curb pollutants, and clean up its environment. Chinese steel producers use one-fifth more energy per ton than the international average.¹¹³ As of May 2007, the Chinese government imposed a 5–10 percent export tax on 53 different kinds of steel and iron products made under high-pollution circumstances in industrial areas. China is also using nanotechnology R&D and, to a lesser extent, biotechnology R&D to address its environmental problems in such areas as water pollution, automobile pollution, and green chemistry (see tables 5 and 6). The State Environmental Protection Agency (SEPA), which is in charge of China's environmental programs, plans to spend RMB6 billion (approximately US\$857 million) on S&T during the

¹¹⁰ To illustrate the range of R&D, one article published in 2007 was a doctoral dissertation conducted at Jiaotong University in Beijing on key technology research of near-zero emission coal utilization and system integration. Another one was a comprehensive report on the 50-year history of China's Coal Research Institute. For the doctoral dissertation, see China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp; for the history of the China Coal Research Institute, see China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN:0253-2336.0.2007-01-000; accessed February 13, 2008).

¹¹¹ Dan Lynch, Bruce Jacobs, and Wenran Jiang, "Thirty One Nuclear Power Plants in China by 2020," C-Pol discussion thread, August 19, 2007.

¹¹² Z. Zhang and S. Yu, "Future HTGR Developments in China after the Criticality of the HTR-10," *Nuclear Engineering and Design*, no. 1 (October 2002): 249–57.

¹¹³ Lan Xue, "Recent Developments of Chinese Government Policies on High-Tech Industries and Innovation."

period covered by the 11th Five-Year Plan (2006–2010).¹¹⁴ However, SEPA focuses primarily on enforcing standards rather than facilitating innovation. In addition, the activities of SEPA and the CAS do not encompass R&D in universities or industries, which covers a wide range of sectors, from the automobile industry to the manufacture of boilers, industrial control technology, construction, and other industries.¹¹⁵

Americans who study Chinese environmental programs note that Western scientists have played a major role in initiating Chinese R&D in the environmental sphere.¹¹⁶ For example, Yale University supports a large forestry management program; the University of Wisconsin has an environmental and conservation project (IGERT); Harvard's China Project includes a large environmental component; and the Global Environmental Facility in Germany is actively involved in collaborative projects in China.¹¹⁷ However, according to Jostein Nygard, coeditor of the 2001 World Bank report, *China: Air, Land, and Water*, Chinese scientists are becoming more involved in developing indigenous environmental projects.¹¹⁸

Corliss Karasov, a freelance science writer at the University of Wisconsin who has conducted numerous interviews with scientists in China, notes that environmental programs, by their very nature, are complex and multidisciplinary and, therefore, do not fit into China's single-discipline educational curricula. For example, the quality of Chinese education in biology is far below standards required to support R&D in biodiversity, a necessary component of environmental planning.¹¹⁹ Xiping Xu, an epidemiologist at Harvard University, has identified inadequate training and lack of communication among various subdisciplines as the major infrastructure problem in Chinese environmental health science programs.¹²⁰

¹¹⁴ Corliss Karasov, telephone conversation.

¹¹⁵ Richard P. Suttmeier, e-mail message to author, February 14, 2008.

¹¹⁶ Jennifer Turner, Director of China Environment Forum, Woodrow Wilson International Center for Scholars, e-mail correspondence with the author, February 13, 2008.

¹¹⁷ Corliss Karasov, telephone conversation with the author, February 14, 2008. The following Web sites provide information on China's environmental programs: Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, http://belfercenter.ksg.harvard.edu/project/10/energy_technology_innovation_policy.html; Harvard China Project, Harvard School of Engineering and Applied Sciences and Harvard University Center for the Environment, <http://chinaproject.harvard.edu/>; Yale School of Forestry and Environmental Studies, "Region: China," Yale University, http://environment.yale.edu/topics/region_china/; Global Environment Facility, http://www.gefweb.org/What_is_the_GEF/what_is_the_gef.html; World Resources Institute, China Program, Washington, DC, <http://www.wri.org/profile/deborah-seligsohn>; and Cleaner Production in China, http://www.chinacp.com/eng/cporg/cporg_sepa.html.

¹¹⁸ World Bank Group, *China: Air, Land, and Water* (Washington, DC, 2001).

¹¹⁹ Corliss Karasov, "The Capacity to Change: Building Global Environmental Health Expertise," *Environmental Health Perspectives* 111, no. 9 (July 2003); and Corliss Karasov, telephone conversation.

¹²⁰ Karasov, "The Capacity to Change."

In the meantime, the inadequacy of China's R&D, educational programming, and environmental planning make the country vulnerable to environmental catastrophes. For example, China's national campaign to build the Three Gorges Dam Project, the world's largest hydroelectric plant, already has precipitated an environmental disaster. Although China intended the dam to control floods and lessen the country's dependence on coal power, scientists now predict that the dam will have a major detrimental impact on China's water quality.¹²¹

China's Space Program

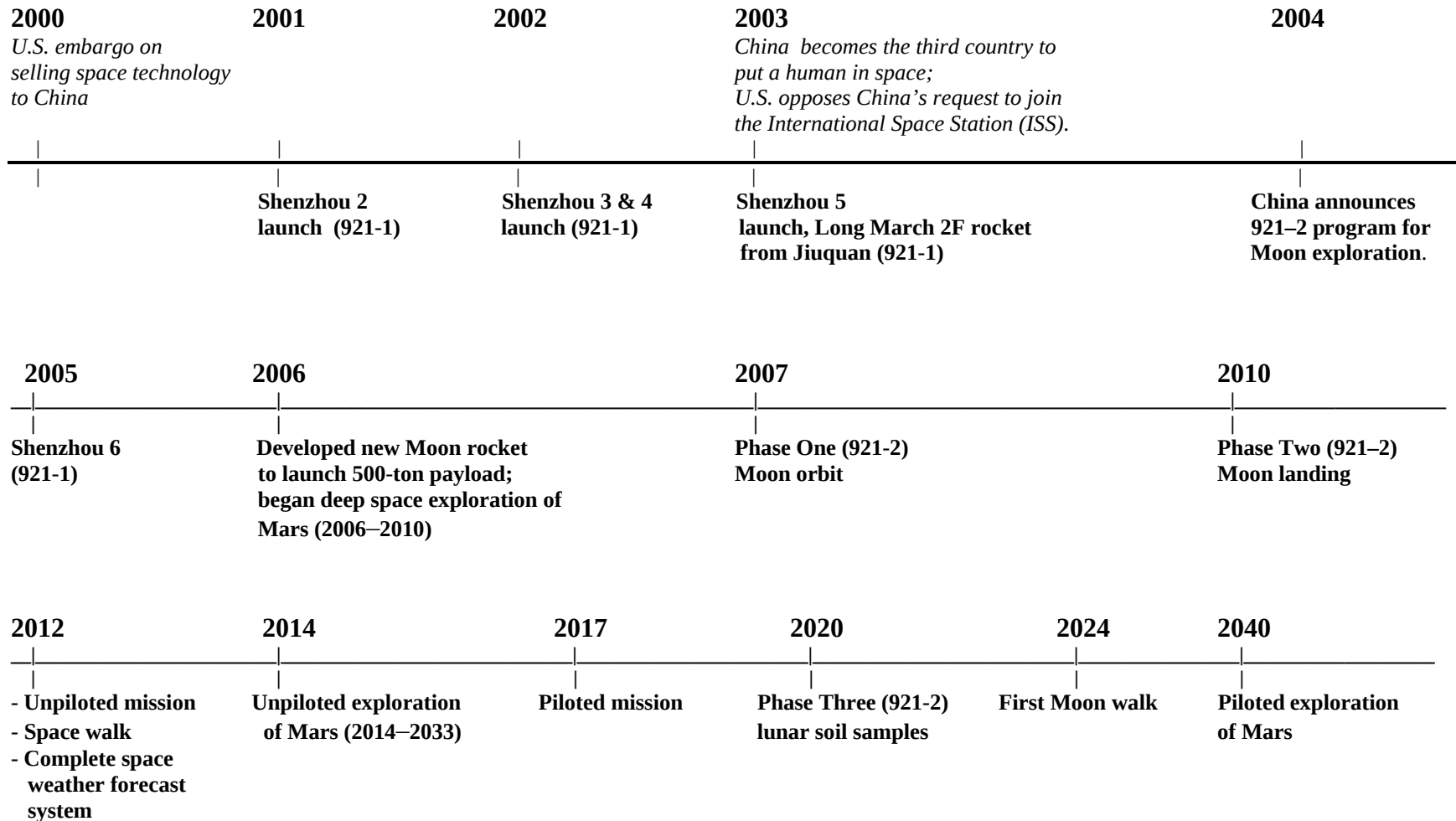
According to the U.S. Office of the Secretary of Defense's 2007 report on China's military power, China aims to implement projects involving piloted space flight and lunar probes between 2010 and 2020. In addition, it hopes to achieve R&D breakthroughs in aerospace equipment, including reconnaissance (i.e., earth-resource systems with military applications); satellite navigation systems; acquisition of mobile data reception equipment; small satellite launches for oceanographic and environmental R&D; and antisatellite weapons tests.¹²² Figure 2 provides a chronology, beginning in 2000, of China's past and projected aerospace accomplishments. Over the next 20 years, China's space program, combining the advantages of the PRC's nationalistic drive to succeed, the program's articulated R&D infrastructure, high levels of funding, and a predisposition to excel in engineering, may achieve major advances in a number of high-technology fields.¹²³

¹²¹ Joseph Kahn and Jim Yardley, "As China Roars, Pollution Reaches Deadly Extremes," *New York Times*, August 26, 2007, 1, 6–7. For an extensive analysis of the politics of energy and the environment in China, see Elizabeth C. Economy, *The River Runs Black: The Environmental Challenge to China's Future* (Ithaca, New York: Cornell University Press, 2004); and Kristen A. Day, ed., *China's Environment and the Challenge of Sustainable Development* (Amana, New York: M.E. Sharpe, 2005).

¹²² United States, Department of Defense, Office of the Secretary of Defense, *Military Power of the People's Republic of China 2007* (annual report to Congress, Washington, DC, 2007), 20–21.

¹²³ Richard P. Suttmeier, "A New Technonationalism? China and the Development of Technical Standards," *Communications of the ACM* 48, no. 4 (April 2005): 35–37.

Figure 2. Timeline of China's Space Program



Source: Based on information from “Chinese Space Program,” Wikipedia, http://en.wikipedia.org/wiki/China_space_program (accessed January 2008); Marcie S. Smith, “China’s Space Program: An Overview” (CRS Report for Congress, No. RS21641, Congressional Research Service, Library of Congress, Washington, DC, updated October 18, 2005), <http://www.fas.org/sgp/crs/space/RS21641.pdf>; United States, Department of Defense, Office of the Secretary of Defense, *Military Power of the People’s Republic of China 2007* (Annual Report to Congress, Washington, DC, 2007); and Patrick M. Miller, “Non-U.S. Space Programs: China Profile and Potential Contributions to Collaborative Efforts” (report, Federal Research Division, Library of Congress, Washington, DC, February 2005).

The space program's R&D infrastructure includes the following four government-sponsored entities and two academic institutions:

- China National Space Administration (CNSA), an agency within the China Commission of Science, Technology, and Industry for National Defense (COSTIND), which interfaces with space agencies in other countries
- China Aerospace Corporation (CASC), which controls all national programs
- Chinese Academy of Launch Vehicle Technology, an SOE, which produced the Long March rocket
- China Aerospace S&T Corporation, also an SOE, which produces satellites
- Tsinghua University
- Harbin Institute of Technology

In addition to these, China has four launch centers—Jiuchuan, Xichang, Taiyuan, and Wenchang—and several monitoring and control centers.¹²⁴

Analysts note that whereas the Chinese space program receives high levels of funding, its budget fluctuates, depending on other economic factors, particularly relating to agriculture and the environment. The annual budget for China's space program usually is between US\$1.4 billion and US\$2.2 billion.¹²⁵ By 2005 China had spent US\$2 billion on versions 1–5 of the Shenzhou spacecraft and US\$110 million on Shenzhou 6.

In addition to China's space program plans listed on figure 2, the 11th Five-Year Plan (2006–10) will include the development of the Beidou navigation system of 60–70 satellites. Furthermore, China plans to launch the world's largest solar space telescope in 2008, as well as a Space Hard X-Ray Modulation telescope by 2010. The Federal Research Division of the Library of Congress has produced a detailed account of the activities of China's space program through 2005.¹²⁶

Between 2000 and 2007, CNKI indexed approximately one dozen articles on space technologies from Chinese academic journals, covering topics such as

¹²⁴ Marcia S. Smith, "China's Space Program: An Overview" (CRS report for Congress, no. RS21641, Congressional Research Service, Library of Congress, Washington, DC, updated October 18, 2005), 1, <http://www.fas.org/sgp/crs/space/RS21641.pdf>.

¹²⁵ Marcia S. Smith, 4.

¹²⁶ Patrick M. Miller, "Non-U.S. Space Programs: China Profile and Potential Contributions to Collaborative Efforts" (report, Federal Research Division, Library of Congress, Washington, DC, 2005), 1–22.

- microgravity research for the International Space Station (ISS) program;¹²⁷
- Asian-Pacific space geodynamics Very Long Baseline Interferometry (VLBI) experiments;¹²⁸
- biomass production chambers used at the Kennedy Space Center;¹²⁹
- spacecraft systems designed by NASA;¹³⁰
- risk-management in China's space program;¹³¹
- American space-based laser programs;¹³²
- quick-response systems programs in the United States;¹³³
- national security and space technology in the United States;¹³⁴
- new visions in U.S. space explorations;¹³⁵
- China's piloted space engineering program;¹³⁶
- high-energy physics and simulation studies;¹³⁷
- China's lunar exploration program;¹³⁸
- meta-syntheses in the piloted space program;¹³⁹ and,

¹²⁷ *World Sci-Tech R&D*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 51-1468/N.0.2000-02-004; accessed February 7, 2008).

¹²⁸ *Science in China*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1006-9283.0.2001-02-013; accessed February 7, 2008).

¹²⁹ *Space Medicine and Medical Engineering*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1002-0837.0.2001-02-016; accessed February 7, 2008).

¹³⁰ *Spacecraft Environment Engineering*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1673-1379.0.2002-04-009; accessed February 7, 2008).

¹³¹ *Chinese Space Science and Technology*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1000-758X.0.2002-06-005; accessed February 7, 2008).

¹³² *Laser and Infrared*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1001-5078.0.2003-03-001; accessed February 7, 2008).

¹³³ *International Aviation*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1000-4009.0.2003-06-026; accessed February 7, 2008).

¹³⁴ *Peace and Development*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1006-6241.0.200-04-006; accessed February 7, 2008).

¹³⁵ *International Aviation*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1000-4009.0.2004-09-023; accessed February 7, 2008).

¹³⁶ *Studies in Science of Science*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1003-2053.0.2005-02-000; accessed February 7, 2008).

¹³⁷ *Chinese Journal of Space Science*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 0254-6124.0.2005-02-007; accessed February 7, 2008).

¹³⁸ *Engineering Science*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1009-1742.0.2006-10-004; accessed February 7, 2008); and *Engineering Science*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1000-4009.0.2003-06-026; accessed February 7, 2008).

- thermoelectric generators in lunar exploration.¹⁴⁰

Advances in Military Technology

Analysts agree that China's military budget has increased dramatically over the past 10 years, although they differ in their estimates of China's defense expenditure. In May 2007, *Jane's Sentinel Security Assessment* suggested a range in the military budget between US\$50 billion and US\$70 billion.¹⁴¹ An earlier 2005 RAND Corporation study provided an estimate of around US\$45 billion.¹⁴²

Because of the uncertain nature of Chinese statistics, the fact that the Chinese government does not include all military-related expenditures, such as those for R&D, in its official published defense budget, and complications in formulating exchange rates between China and the developed world, arriving at a funding level for Chinese military R&D is problematic. Moreover, several revenue sources, including the General Armaments Division, the Commission of Science, Technology, and Industry for National Defense (COSTIND), the Ministry of State Science and Technology, and various defense industries, support military-related R&D, further complicating calculations of China's military R&D expenditures. Since 2006 *The Military Balance*, a publication of the International Institute for Strategic Studies in London, has endeavored to estimate the true level of China's total defense expenditures, including those for R&D, using a methodology that combines official Chinese statistics, purchasing power parity, market exchange rates, and other factors. Based on this methodology, *The Military Balance* estimates that China's expenditures on military R&D and new product expenditure (S&T) combined amounted to US\$5.82 billion in 2003, US\$7.71 billion in 2004, and US\$9.64 in 2005.¹⁴³ *The Military Balance* cautions, however, that its methodology at best

¹³⁹ *Engineering Science*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: ISSN: 1009-1742.0.2006-12-001; accessed February 7, 2008).

¹⁴⁰ *Journal of the Chinese Academy of Electronics and Information Technology*, China Knowledge Infrastructure (CNKI) Database, http://online.eastview.com/login_china/index.jsp (accession number CNKI: SUN:KJPL.0.2007-03-020; accessed February 7, 2008.)

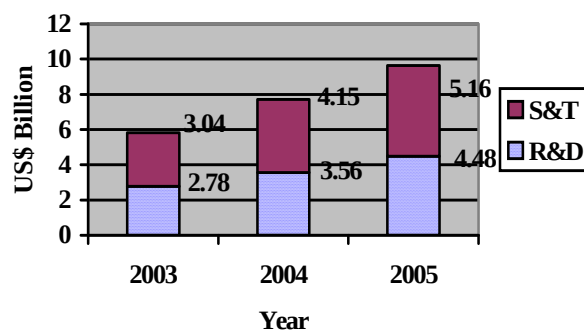
¹⁴¹ "Executive Summary, China, Defence," *Jane's Sentinel Security Assessment – China and Northeast Asia*, May 2007 (accessed through Intelink, March 15, 2008), 4.

¹⁴² Evan S. Medeiros, Roger Cliff, Keith Crane, and James C. Mulvenon, *A New Direction for China's Defense Industry*, Santa Monica, California: RAND, 2005, 4-22. See also GlobalSecurity.org, "China's Defense Budget," <http://www.globalsecurity.org/military/world/china/budget.htm>.

¹⁴³ International Institute for Strategic Studies, *The Military Balance* (London: Routledge, 2006, 2007, 2008) 369, 341, 369.

gives a notional value for military R&D spending. See figure 3 for a graphical depiction of this data. The methodology, as published in *The Military Balance 2006*, is attached to this paper in Appendix D.¹⁴⁴

Figure 3: Estimated Funding of China's Military R&D and S&T (US\$ billion), 2003–2005



Source: International Institute for Strategic Studies, *The Military Balance* (London: Routledge, 2006, 2007, 2008) 369, 341, 369.

In general, analysts who have access to public sources of information believe that structural factors—that is, how the Chinese military is organized bureaucratically—severely limit China's ability to develop a stable R&D budget. However, analysts believe that the focus is on acquiring technology from other countries instead of developing it indigenously. Furthermore, the IT and computer industries serve as hubs for much of China's success in R&D, military or otherwise. France, Israel, Russia, the United Kingdom, and the United States are China's main suppliers in the IT and computer industries of technologies that have “dual use” (civilian and military) applications.

In 2003 Li Jinai, a member of the Central Military Commission and director of the General Armament Department of the People's Liberation Army (PLA), inaugurated China's military IT alliance, endorsing a three-pronged policy of:

1. Selective modernization of the aerospace industry, missile manufacturing, electronics technology, and other crucial high-technology equipment, such as command, control, computers, communications, intelligence, surveillance, and reconnaissance (C4ISR) and accurate strike weapons;

¹⁴⁴ International Institute for Strategic Studies, *The Military Balance*, 2006, 77–81.

2. Integration of civilian and military R&D systems; and
3. Acquisition of advanced foreign weapons equipment, materials, and technologies¹⁴⁵

In 2002 the Beijing Military Representative Bureau's cooperative program began to integrate the civilian and military systems, involving the national defense departments of universities, colleges, and scientific research institutes in five cities—Beijing, Changsha, Shanghai, Shenyang, and Wuhan.¹⁴⁶

At the Rand Corporation, Evan Medeiros identified the greatest failure of China's defense industry as the PLA's long-term reliance on purchases of major weapon systems from foreign countries, mainly Russia and Israel. For example, under a co production agreement, Russia supplied technical expertise for China to build the F-11 fighter; Israel was pivotal in China's work to build the J-10 fighter.¹⁴⁷ China accelerated its foreign procurement of military equipment during the mid-1990s, focusing on advanced, fourth-generation fighter aircraft, particularly modern aircraft with advanced air defense and air-to-surface capabilities; long-range, land-based air defense systems; advanced diesel-electrical submarines; jet engines; and advanced defense electronics technologies. Medeiros believes that China's numerous purchases of advanced foreign weapons systems indicate structural weaknesses in the PLA.¹⁴⁸

China exports military products, as well as importing them. This implies that China has a dense network of both customers and suppliers and will increase its role as a global player not only economically but also militarily.¹⁴⁹ For example, China's Huawei Shenzhen Technology Company has developed customer bases in 45 countries for Chinese military equipment. In addition, Chinese military exporters have penetrated geographic areas that Western telecommunications companies generally ignore, including Africa, Russia, and India. Another Chinese company, Julong Information Technology (Group) Co., Ltd. has developed cooperative

¹⁴⁵ Medeiros et al., *New Direction for China's Defense Industry*, 24-26.

¹⁴⁶ Medeiros et al., *New Direction for China's Defense Industry*, 25.

¹⁴⁷ *Jane's Sentinel Security Assessment* also reports that China "is on its way to" acquiring more than 300 Sukoi fighters, 12 Kilo-class submarines, 4 Sovremenny-class destroyers, and hundreds of S-300 antiaircraft missiles from Russia. However, these acquisitions do not help China upgrade its indigenous R&D capability.

¹⁴⁸ Medeiros et al., *New Direction for China's Defense Industry*, 11.

¹⁴⁹ For more information, see the transcript of a Carnegie Debate on Capitol Hill on June 11, 2007, in which China specialists Bates Gill, Dan Blumenthal, and Michael Swaine discuss the challenges ahead in China's international role as a responsible stakeholder. The debate proposition was based on China's role in seven key areas of international activity: 1) Counter-proliferation (especially re North Korea and Iran); 2) Asian security; 3) Energy security; 4) Economic development and assistance; 5) Peace-keeping and enforcement; 6) The maintenance of an open, rules-based trading system; and 7) Human rights (especially the Darfur issue). See <http://www.carnegieendowment.org/events/index.cfm?fa=eventDetail&id=998&&prog=zch>.

R&D agreements with companies in Canada, Colombia, Israel, Japan, Russia, and the United States.¹⁵⁰ This means that China will become an even more important player economically in IT and that it uses IT to develop the Chinese military infrastructure domestically.

Military Aviation

The Chinese government stimulates technological progress in China's aviation industry with China's 863 Program, which supports R&D in aviation. For example, the 863 Program funded China's first technology park, Zhongguancun, specifically to promote advances in military aviation. However, the Ministry of Aerospace Industry is neither accountable to the public for the successes and failures of its programs nor stimulated by competition with private R&D. This lack of competition within China has impeded S&T development in this sector. Furthermore, although the actual number of personnel employed in R&D in the military aviation sector is comparable to that in the United States, the level of training of scientists and engineers is less so. Moreover, the best and the brightest scientists and engineers entering careers in the aviation industry transfer to FIEs.¹⁵¹

The design and production of combat aircraft, such as the JH-7/FBC-1, exemplify the Chinese military aviation industry's technological capability. China is in the process of producing fourth-generation aircraft, the J-10/F-10, and may already have completed the indigenously designed Z-10 helicopter. However, as of 2005, the industry had not mastered serial production of complex, fourth-generation aviation platforms.¹⁵²

Missile Technology

Because ballistic and cruise missiles are central to China's military operational planning, missile technology is a leading sector in the defense industry. China's missile defense field relies on R&D conducted in its major universities, Beijing University, Tsinghua University, East China University of Science and Technology, and Northwest Polytechnic University. These universities are responsible for the majority of China's R&D in the military sector, and, through cooperative

¹⁵⁰ Medeiros et al., *New Direction for China's Defense Industry*, 219, 223.

¹⁵¹ Medeiros et al., *New Direction for China's Defense Industry*, 22.

¹⁵² The RAND study used many different sources to compile this information, including technical details from more than 100 journals in the Chinese aerospace sector. The study often cites China's *Science and Technology Daily*.

international programs, they successfully transfer technology from foreign countries into the defense industry.¹⁵³

Two large holding companies—the China Aerospace Science and Technology Corporation (CASC) and the China Aerospace Science and Industry Corporation (CASIC)—produce most of China's missiles. Other companies producing missiles include the China Aviation Industries Corporation I and II (AVIC I and AVIC II) and the China North Industries Group Corporation (CNGC); smaller companies have developed the DF-11 (CSS-7) and DF-15 (CSS-6) missiles. According to the Rand study, as in the military aviation sector, the talent pool of scientists and engineers in the missile technology sector is diminishing, as R&D opportunities offered in foreign academic institutions draw experts in the field. However, because Chinese researchers consider work in the missile industry to be prestigious, the human resource base in missile manufacturing remains more stable than in the aviation sector.¹⁵⁴

China's missile production enterprises produce new advanced ballistic and cruise missiles, including serial production and variants of the DF-11 and DF-15 short-range ballistic missiles. The industry is in the process of deploying land-attack cruise missiles; fast and highly accurate antiship cruise missiles; modern, long-range, surface-to-air missiles; and antiradiation missiles.¹⁵⁵ Although China has basic land-attack cruise missile capability, the missile technology sector has not produced an array of precision ground-attack missiles similar to those the United States used in the 1991 Gulf War. In this sector as in others, the Chinese leadership's strategy of relying on technology transfers from foreign countries keeps China's missile system perpetually out-of-date.

China's multibillion-dollar nuclear weapons industry includes a small, but formidable, nuclear deterrence force of 400 weapons—250 strategic and 150 tactical warheads. In comparison, the United States and Russia each possess 10,000 nuclear warheads. China has reverse-engineered the Moskit SN-X22, a supersonic naval cruise missile that can carry a nuclear warhead. In addition, China has advanced capabilities in hypersonic cruise and anti-aircraft missiles that the United States cannot yet counter.¹⁵⁶

¹⁵³ Medeiros et al., *New Direction for China's Defense Industry*, 51.

¹⁵⁴ Medeiros et al., *New Direction for China's Defense Industry*, 65–67.

¹⁵⁵ U.S. Federal News Service, "Debate 3: Is China's Military Modernization a Growing Threat?"; and Ashley Tellis, "China's Military Space Strategy," *Survival* 49, no. 3 (September 2007): 41–72.

¹⁵⁶ Carnegie Endowment for International Peace, New Vision Program, Debate Series: Reframing China Policy Debate 3: The Implications of China's Military Modernization, "Is China's Military Modernization Program a

Shipbuilding

As the world's third largest shipbuilder, China participates actively in international commercial markets, thereby gaining access to foreign equipment, capital, and technology.¹⁵⁷ Although the China State Shipbuilding Corporation (CSSC) and the China Shipbuilding Industry Corporation (CSIC) are SOEs, reporting directly to the State Council, new and expanding interactions between R&D institutes and academic organizations within China have had a positive effect on R&D and design capabilities in this field. However, the shipbuilding industry continues to suffer from a lack of experienced scientific research, administrative, and management personnel.¹⁵⁸

Beginning with low-level production in the 1980s, the shipbuilding industry has met a growing demand for Chinese-built vessels, producing sophisticated naval platforms. In 2005 China supplied 18 percent of the global shipbuilding market and ranked number three in the world in terms of shipbuilding output, behind Japan and the Republic of Korea (ROK), which together accounted for about 70 percent of the global shipbuilding market. China quadrupled capacity from 3.5 million deadweight tonnage (dwt) in 2002 to 12 million dwt in 2005.¹⁵⁹

The MLP lays out the following targets for China's shipbuilding industry:

- the production of ships that meet international levels of technical sophistication;
- an annual output of 17 million dwt;
- an increase in the annual production capacity of medium- and low-speed ship diesel engines to 4.5 million kw and 1,100 units respectively for the domestic market; and
- local production of more than 60 percent of China's ship equipment.

In addition, the plan calls for improvements in the capacity to design ships and marine equipment, in the infrastructure for building heavy ships, and in innovation capabilities.¹⁶⁰

Growing Threat to the United States and Asia?" Washington, DC, February 6, 2007, http://www.carnegieendowment.org/files/debate_3%20final%20transcript.pdf. Furthermore, some analysts suggest that China possesses submarine warfare capability exceeding that of the United States. See discussion in U.S. Federal News Service, "Debate 3: Is China's Military Modernization a Growing Threat?"

¹⁵⁷ Guangzhou, *Guangdong Zaoshan* [China's Push to Become World's Top Shipbuilding Country], March 2007, 1–3, <https://www.opensource.gov/> (OSC document no. CPP20080204465001).

¹⁵⁸ U.S.–China Commission, *Report to the U.S. Congress*, 107.

¹⁵⁹ ChinaView, "China Maps out Goal for Shipbuilding Industry," September 25, 2006, <http://www.newsgd.com/news/picstories/200609250005.htm> (accessed September 8, 2008).

¹⁶⁰ ChinaView, "China Maps out Goal for Shipbuilding Industry."

Between 2006 and 2010, China plans to accelerate the construction of shipbuilding bases in the Bohai Rim, the Yangtze River delta, and the Pearl River delta and focus on the design and manufacture of:

- high-tech, high-function special ships, and 100,000-dwt and larger ships;
- passenger ships, passenger-cargo ships, and train ferries;
- liquefied natural gas (LNG) and liquefied petroleum gas (LPG) ships of 5,000 cubic meters and above;
- 3,000 twenty-foot equivalent units (TEU) and greater container ships;
- marine power systems, power plants, and special support machines;
- large deep-sea fishing boats, marine drill vessels, oil rigs, marine floating production storage and offloading (FPSO) structures and other offshore engineering equipment;
- ship control and automation products, telecom and navigation equipment, instruments and meters and other marine equipment.¹⁶¹

In order to compete globally, China is encouraging foreign investment through equity-for-technology and market-for-technology deals. According to the plan, foreign shipbuilders are permitted to “reorganize, acquire or jointly fund shipbuilding enterprises, medium- and low-speed ship diesel engine manufacturing enterprises and crankshaft manufacturing enterprises in China, provided they hold no more than 49 percent of the shares.”¹⁶²

Defense Electronics

At the highest levels, China's leaders support advances in defense electronics. Defense electronics encompasses both telecommunications and information communications technology (ICT). Although the Chinese military supports the development of both these sectors, they are not part of China's defense industrial complex. Telecommunications and ICT are S&T policy priorities because both affect the stability of China's national economy outside of the military sector. The military helps fund and staff commercially oriented firms, which also receive lines of credit from the state R&D infrastructure and are endowed with funds from the state banks and the previously discussed 863 Program.¹⁶³

¹⁶¹ “China Maps out Goal for Shipbuilding Industry.”

¹⁶² “China Maps out Goal for Shipbuilding Industry.”

¹⁶³ Medeiros et al., *New Direction for China's Defense Industry*, 216, 230.

Four private companies emerged from the state research institutes—Huawei, Zhongxing, Datang, and Julong. Huawei is China's largest telecommunications equipment manufacturer. Zhongxing is another of the country's top telecommunications equipment producers, holding more than 300 patents through WIPO. Datang, an outgrowth of one of China's leading R&D institutions, currently invests in indigenous research in defense electronics. Julong is China's ninth largest telephone exchange manufacturer.

The China Electronic System and Engineering Corporation (CESEC) is a state-owned systems integrator of technologies from multiple outside vendors.¹⁶⁴ Key to the PLA's telecommunications network, CESEC supports mobile communications to secure telephone lines, mobile radio paging, and fiber optic cables.

The defense electronics industry, with its solid human resource base, no longer needs to directly import Western technology. However, conflicts of interest arise when MNCs, eager to supply the Chinese market, do not take into account U.S. national security interests. A RAND study emphasizes this point: "Thanks to the irresistible siren song of China's huge IT market, foreign companies want to transfer cutting-edge technology for the promise of market access."¹⁶⁵

Telecommunications

As an instrument for information dissemination, the introduction of convergence technologies to incorporate data communications, including the Internet and cable television (CATV), is rapidly expanding the definition of telecommunications in China. In the 1990s, the Chinese leadership made development of Internet and Internet protocol (IP) services a high priority; however, significant advances in this area did not occur until 2000.¹⁶⁶

During the 1990s, a period of dramatic improvements in engineering and network operations, China happened to be participating in a joint venture with the telecommunications company Scientific Atlantica, enabling it to import cutting-edge technology. In 2003 the Huawei Corporation began producing routers, the Internet's core technology, at 50 percent of the price of its U.S. competitors. At present, except for sales and marketing, Asian and European countries

¹⁶⁴ Medeiros et al., *New Direction for China's Defense Industry*, 241.

¹⁶⁵ Medeiros et al., *New Direction for China's Defense Industry*, 206.

¹⁶⁶ Robert C. Fonow, "Beyond the Mainland: Chinese Telecommunications Expansion," *Defense Horizons*, no. 29 (July 2003): 1–8, http://www.ndu.edu/ctnsp/defense_horizons.htm.

prefer to employ China's telecommunications services, considering U.S. products too expensive.¹⁶⁷

In mobile telephony, Alcatel Shanghai Bell has achieved greater technological mastery than other Chinese firms. Foreign firms such as Siemens, Nokia, Ericsson, and Motorola provide advice on technical standards. Robert Fonow, former vice president of Alcatel Shanghai Bell, states that Global Crossing, Asia Global Crossing, Level 3, and PSINet enhanced China's ability to monitor and interdict communications traveling across its network. With respect to telecommunications and information warfare, according to Fonow, "The first question is to what degree can the former assets of Global Crossing, Level 3, and PSINet be used to control the Asian international telecom system or provide the capability for espionage and network warfare (netware). The answer is that these assets enhance China's capability to monitor and interdict communications that travel across its network. Up to 95 percent of the Department of Defense telecommunications traffic uses the international telecommunications system. Most diplomatic or military traffic destined for North, East, and South Asia will traverse networks now owned by Chinese interests. Indeed, some of this traffic passes through facilities on the Chinese mainland."¹⁶⁸

Regional Trends in Information Technology

China's most dramatic technological advances over the past five years have been in IT. An often-cited example is China's Dawning 4000A computer, which in 2004 ranked tenth on the TOP500 list of the world's top high-performance computers.¹⁶⁹ In 2003, for example, FIEs represented 85.4 percent of the total volume of China's high-technology exports. Even four years ago, FIEs exported 92.5 percent of all computers and 96.4 percent of all mobile communications manufactured in China.¹⁷⁰ To encourage indigenous innovation, a major goal of the Chinese government is to learn from FIEs. To explore the dynamics of China's innovation potential, its interactions with foreign countries, and government relationships with local cultures, Adam

¹⁶⁷ Fonow, 5.

¹⁶⁸ Fonow, "Beyond the Mainland," 1–8.

¹⁶⁹ Denis Fred Simon, "Hearing on Chinese High Technology Development" (paper presented to the U.S.–China Economic and Security Review Commission, Stanford University, Palo Alto, California, April 21–22, 2005), <http://www.uscc.gov/>.

¹⁷⁰ Simon, "Hearing on Chinese High Technology Development."

Segal conducted research on China's IT sector in Shanghai, Beijing, Guangzhou, and Xi'an.¹⁷¹ His findings are described below.

Shanghai

According to Segal, Shanghai is unique in that it is the only location in which the national government plays a prominent role in funding and guiding its direction of innovation in the IT sector. This occurs because local Shanghai planners cultivate two business networks, one involving businesses and customers in Japan and Korea and the other in China's own defense industry.¹⁷² The local government has implemented the ideal of "capitalism with Chinese characteristics" by directing all foreign investments to a few large, military-based SOEs. To accelerate IT developments, the Chinese government allocates funds through the military sector, but foreign companies in China dominate the export market. To promote competition, local planners developed science budgets that allow companies to bid on infrastructure projects. However, party leaders become involved in the day-to-day operations of the SOEs, micromanaging infrastructure projects and investments and impeding Shanghai's innovation potential.¹⁷³

Shanghai fills a niche in the manufacture of hardware, especially integrated circuits. It is the nation's largest producer of semiconductors.¹⁷⁴ On the other hand, the local scientific community does not foster Internet startups and depends on local government to provide capital, technology, and skilled personnel.

Beijing

In contrast to Shanghai, Beijing's city planners distance themselves from the central government, with local planners providing funds to entrepreneurs to develop the IT sector. Funds are limited, and entrepreneurs do not have access to venture capital.¹⁷⁵ Moreover, unlike in Shanghai, the local S&T community in Beijing models itself on U.S. Silicon Valley, which is considered to be entrepreneurial and oriented toward basic research, rather than developing

¹⁷¹ Segal, *Digital Dragon*, 22.

¹⁷² Segal, *Digital Dragon*, 128.

¹⁷³ Segal, *Digital Dragon*, 97.

¹⁷⁴ Segal, *Digital Dragon*, 20.

¹⁷⁵ Segal, *Digital Dragon*, 55.

relationships with businesses in Asia. Beijing's IT sector leads the country in software development and Internet technologies. While maintaining formal, distant relationships with the national government, Beijing's IT sector involves itself in large infrastructure projects and invests in the local science budget.¹⁷⁶

Guangzhou

Guangzhou provides yet another configuration of government and entrepreneurial involvement in S&T. Its S&T community, deriving its inspiration from South Korea, Hong Kong, Taiwan, and Singapore, does not work with the local government. Instead, the S&T community comprises numerous small, collective enterprises, relying on FDIs and joint ventures. Because IT firms remain separate from the local government, they do not have access to government R&D funding, technology, and skilled personnel. Guangzhou lacks the human capital base of talented scientists and researchers needed to establish IT companies.¹⁷⁷

Xi'an

Like Shanghai, local government planners in Xi'an support SOEs and, characteristically, micromanage investments in IT companies. However, in contrast to the other three cities, Xi'an is isolated geographically from the rest of the country and from foreign investment. The Chinese concept, *wai*, meaning *outside*, is particularly meaningful in this context. Anything outside of Xi'an is *wai*, including, but not limited to, people and political parties.¹⁷⁸ With no *wai* influence, Xi'an entrepreneurs diversify by producing an array of technically simple IT systems, at the same time developing close ties with local authorities. Quasi-governmental enterprises support high levels of interaction among the functional units of marketing, R&D, and sales, while local universities band together to support R&D. One major obstacle to developing IT in Xi'an is that the education and military sectors do not interact with each other. It is a classic situation of the left hand (i.e., research institutes under the Education Commission) not knowing what the right hand (i.e., IT defense industry) is doing. Because the defense industry provides a strong base for

¹⁷⁶ Segal, *Digital Dragon*, 78, 100.

¹⁷⁷ Segal, *Digital Dragon*, 123, 128, 132, 150, 157.

¹⁷⁸ The Chinese term for foreigner, *waiguoren*, literally translates as *outside country person*. In the 1980s, Taiwan's first political party to oppose the dominant KMT was called *dangwai*, meaning *outside of the party*.

IT, the separation of higher education from national defense is not educating according to the needs of the industry.¹⁷⁹

Table 7 summarizes different regional approaches in the IT industry. Because IT drives many other technologies, it is likely that these regional and cultural characteristics influence the direction of R&D in military technology, defense electronics, energy technology, environmental technology, biotechnology, space, and nanotechnology.

¹⁷⁹ Segal, *Digital Dragon*, 158.

Table 7. Regional Differences in China's IT Industry

City	Domestic Partners for the S&T Community	International Models	Niche Technologies	Issues
Shanghai	Strong military ties Strong national and local government involvement	Japan Korea	Integrated circuits; semiconductors	Over-involvement of party leaders
Beijing	Strong ties to local government Distances itself from national government	Silicon Valley (US)	Software development; Internet technologies	
Guangzhou	Works more with foreign investors and joint ventures than local or national government	Norway Korea Hong Kong Taiwan Singapore	Joint ventures	Lack of qualified human capital
Xi'an	Strong support from local government Strong military ties	Isolated from foreign investment	Simple IT configurations	Over-involvement of party leaders Lack of qualified human capital
Source: Adam Segal, <i>Digital Dragon: High Technology Enterprises in China</i> (Ithaca, New York: Cornell University Press, 2003).				

Semiconductors

China has strong R&D capabilities in certain sectors, such as mobile telephone development and chip design where a cluster of firms compete and cooperate with MNCs; a

steady flow of ex-MNC employees and researchers returning from abroad join new firms; and strong consumer markets produce adequate capital.¹⁸⁰

The development of China's semiconductor industry is of ongoing concern to the U.S. government. In 2006 the U.S. Government Accountability Office responded to requests from the U.S. Congress, publishing a report on China's and India's semiconductor industries.¹⁸¹ Although China's semiconductor industry is an entrenched, Soviet-style bureaucracy, hierarchical and not innovative, the industry forms the heart of China's defense electronics sector, supplying the PLA with advanced integrated circuits for use in sensors and weapons systems.¹⁸² However, although China has become important globally as a design and production base for foreign companies, its indigenous workforce does not possess the technical expertise to produce and export new designs. Therefore, China is the world's third largest market for importing semiconductors.¹⁸³

CHINA'S INTERNATIONAL ROLE

Most countries with levels of S&T development comparable to China's have been active in the international community for more than 50 years. In contrast, the PRC joined international organizations later than many of its contemporaries, entering the United Nations in 1971; the International Monetary Fund and the World Bank in 1980; Interpol in 1984; the Asian Development Bank in 1986; and the World Trade Organization (WTO) in 2001.¹⁸⁴ Because of China's late entry into the international community and its subsequent redirection of domestic policies, analysts find it difficult to provide meaningful cross-country comparisons. Table 8 indicates the dates high-profile countries joined international organizations related to S&T. Note that, with the exception of Singapore joining WIPO in 1990, China has lagged behind other countries in joining international organizations.

¹⁸⁰ Oxford Analytica, "National Innovation Systems of India and China," 39.

¹⁸¹ United States, Government Accountability Office, "Offshoring: U.S. Semiconductor and Software Industries Increasingly Produced in China and India" (report no. GAO-06-423, Washington, DC, September 7, 2006), <http://www.gao.gov/new.items/d06423.pdf>.

¹⁸² Segal, *Digital Dragon*, 18.

¹⁸³ U.S.–China Economic and Security Review Commission, *Report to the U.S. Congress*, 90.

¹⁸⁴ Banks et al., *Political Handbook of the World 2007*, 227–37.

Table 8. Dates Countries Became Members of Selected International Organizations

Country	World Bank	World Trade Organization (WTO)	International Atomic Energy Agency (IAEA)	World Intellectual Property Organization (WIPO)
China (PRC)	1980	2001	1984	1980
Brazil	1946	1995	1957	1975
Israel	1954	1995	1957	1970
India	1945	1995	1957	1975
United States	1945	1995	1957	1970
United Kingdom	1945	1995	1957	1970
Japan	1952	1995	1957	1975
France	1945	1995	1957	1974
Australia	1947	1995	1957	1972
Singapore	1966	1995	1967	1990

Source: Based on information from: “Contracting Parties,” World Intellectual Property Organization, http://www.wipo.int/treaties/en/ShowResults.jsp?lang=en&treaty_id=1 (accessed April 17, 2008); “IAEA Member States,” International Atomic Energy Agency Web site, March 2007, <http://www.iaea.org/About/Policy/MemberStates/index.html>; “Members and Observers,” World Trade Organization Web site, July 27, 2007, http://www.wto.org/English/thewto_e/whatis_e/tif_e/org6_e.htm; and “World Bank Group Historical Chronology: Introduction,” World Bank Organization Web site, 2004, <http://web.worldbank.org/WBSITE/EXTERNAL/EXTABOUTUS/EXTARCHIVES/0,,contentMDK:20035653~menuPK:56305~pagePK:36726~piPK:36092~theSitePK:29506,00.html>.

Furthermore, considering that most MNCs established operations in China after China had joined the WTO, China has quickly become a breeding ground for a variety of international exchanges. Foreign affiliates find it beneficial to establish operations in China, where other organizations from around the world also maintain R&D bases. Through exposure to R&D conducted by other firms working in China, and by participating in cooperative research, foreign affiliates develop more new technology in China than they would if they were operating solely from their headquarters at home.

Technology Transfer

To foster indigenous R&D and facilitate technology transfer, the Chinese government initially established nongovernmental enterprises (*minying qiye*) in the 1980s.¹⁸⁵ By the 1990s, a

¹⁸⁵ According to Adam Segal, who did extensive research on China's IT industry, the term *minying qiye* is no longer used. Even though the Chinese leadership intended to introduce the concepts of free enterprise and private property, the Soviet-style bureaucracy, in existence since the 1950s, thwarted further developments. Adam Segal, e-mail correspondence with author, September 27, 2007.

number of government research institutes had reverted to quasi-private sector enterprises, while others became R&D divisions in existing MNCs.¹⁸⁶ As of 2007, a breakdown of ownership showed that roughly 50 percent of China-based enterprises were privately owned, 20 percent each were indirectly or directly state-owned, and 10 percent were collectively owned.¹⁸⁷

Because core technologies in MNCs are controlled either by foreign partners in joint ventures or by company headquarters outside of China, the S&T environment in China for foreign-invested R&D firms is less intensive than for domestic firms, leading Chinese firms to become stable and streamlined business operations. Kathleen Walsh, an American specialist in Chinese S&T, notes that Chinese-owned enterprises appear to be more innovative, efficient, and profitable than many FIEs on the mainland,¹⁸⁸ partly because many foreign-venture capitalists do not understand the practice of government sponsorship in China.¹⁸⁹ However, in high-technology areas, foreign firms continue to dominate. For example, the latest figure, calculated in 2003, indicates that 85.4 percent of the total volume of China's high-technology exports came from FIEs.¹⁹⁰

Academic Exchanges

Higher-education exchanges promote technology transfers by facilitating the flow and integration of knowledge from other countries into Chinese institutions. Presently, one-third of the number of Chinese students and scholars who return from abroad occupy high-level positions in universities and government institutes. In previous decades, the Chinese government guaranteed promotion within his or her research facility to a scientist who participated in a foreign exchange, even for very brief visits abroad. In contrast to the past, Chinese scientists now have greater freedom to change jobs, and the government no longer requires that they remain in one research institute for the duration of their careers.¹⁹¹ However, since 2004 Chinese scientists

¹⁸⁶ Serger and Breidne, "China's Fifteen Year Plan," 140.

¹⁸⁷ OECD, "China: A Synthesis Report," 10 (Figure 1.4).

¹⁸⁸ Walsh, "China's High-Technology Development," 5.

¹⁸⁹ Cao, "Zhongguancun," 664.

¹⁹⁰ Serger and Breidne, "China's Fifteen Year Plan," 146.

¹⁹¹ Peggy Spitzer Christoff, "Relations Between the United States and the People's Republic of China in the Modernization of Science and Technology in China" (PhD dissertation, American University, 1984): 104–5.

have tended to stay longer in the United States, especially in Silicon Valley or similar high-tech environments, learning innovative practices and cutting-edge technologies.¹⁹²

China specialist on S&T Cong Cao has noted that students from elite Chinese universities who enter U.S. graduate programs outperform all other graduate students. For example, between 1999 and 2003, more Chinese students who had received undergraduate degrees from Beijing University and from the University of Science and Technology of China (also in Beijing) went on to obtain doctorates in the physical sciences from U.S. universities than any other student group.¹⁹³ Furthermore, at MIT and the University of California, Berkeley, Chinese students received more than 100 more doctoral degrees in S&T than American doctoral students received. In the physical sciences, 558 Chinese students received doctorates at MIT, and 461 received doctorates at University of California, Berkeley. During the same period, Chinese students with undergraduate degrees from Tsinghua University earned more than twice as many doctorates in engineering at MIT as American students: 344 American students received doctorates in engineering at MIT, compared with 863 Chinese students.¹⁹⁴ However, it is unclear whether the knowledge these students gained in the United States was of the type that might be transferable to the Chinese S&T sector. Over the past few years, more Chinese are returning, after a stint overseas, than in the past. However, for the most part, Chinese who emigrate remain outside of China, particularly in the United States.

At the same time, a decrease has occurred in the number of Chinese foreign-exchange students from 125,179 in 2002 to 114,682 in 2004, a reduction that may be attributable to tightening U.S. restrictions on student visas. Furthermore, foreign universities, following the strategy of MNCs, have set up operations in China, which may cause the continuing decline in the numbers of Chinese students seeking visas to travel abroad. An interesting example of this new strategy is a replica of a Western-style university town just outside of Nanjing, with branches of both American and British universities.¹⁹⁵

Table 9 identifies the types of knowledge China has gained through a variety of bilateral technology exchanges. The third column of the table categorizes learning into four types: program management; best economic business practices; government S&T policy making; and

¹⁹² Segal, "The Civilian High-Technology Economy," 5.

¹⁹³ Cao, "New Key Players," 4.

¹⁹⁴ Cao, "New Key Players," 4.

¹⁹⁵ For an analysis of visa problems, see the U. S. Government Accountability Office's study, "Border Security."

strategies for innovation. Because China's political system differs from those of its exchange partners, the third type of learning, governmental policy making, probably is the least transferable across national boundaries.

Table 9. Chinese Knowledge Transfer from International Exchange Key: 1=Program management 2=Best economic business practices 3=Government S&T policy making 4=Strategies for innovation			
Exchange Country	Description of Learning/Exchange	Type (1–4)	Program Partners
Australia	Coordinating, funding, and evaluating PROs	1	Cooperative Research Centers (CRCs)
	Structuring public/private partnerships for public good projects	3	
Austria	Developing and balancing human resources in PROs	1	Kompetenznetze Centres (K Centers)
	Partnering public and private entities	1	
Canada	Embedding foreign investment in China into national innovation	2	Innovation Portal
	Structuring tax codes for R&D	2	
Denmark	Fostering entrepreneurship	1	Innovation Consortia (Also, the government provides tax deductions for SMEs who collaborate in R&D) Medical Valley businesses
		2	
European Union (general)	Reducing domestic regional imbalances (i.e., in China)	3	CRAFT (Cooperative Research) Innovation Relay Centres CORDIS Technology Marketplace Other government initiatives to target SMEs
Finland	Using ICT as a springboard for innovation	4	Centre of Expertise and Cluster Programmes
	Coordinating, funding, and evaluating PROs	1	
France	Partnering public and private entities	1	Thorrison S.A.
	Structuring public/private partnerships for public good projects	3	
	Taking advantage of dual-use technologies	4	
Germany	Coordinating, funding, and evaluating PROs	1	Pro-Inno Foton Motors Haier Schneider Electronics AG
	Building human resources for SMEs	1	
Ireland	Using ICT as a springboard for innovation	4	N/A
	Embedding foreign investment in China into national innovation	2	
	Establishing SMEs	3	

Table 9. Chinese Knowledge Transfer from International Exchange**Key: 1=Program management****2=Best economic business practices****3=Government S&T policy making****4=Strategies for innovation**

Exchange Country	Description of Learning/Exchange	Type (1–4)	Program Partners
Israel	Developing spin-off technologies	4	N/A
Japan	Expanding basic research Developing and balancing human resources in PROs	3 1	Foton Motors Kelon
Korea (South)	Transitioning from imitation to innovation Expanding basic research Coordinating, funding, and evaluating PROs	4 3 1	Norway Inno-Net Portal Hyundai Ssangyong Motor
Netherlands	Investing overseas Structuring tax codes for R&D	2 2	Huawei Cut-flower cluster businesses
Norway	Establishing SMEs	2	TEFT
Spain	Reducing domestic regional imbalances in China	3	Innovation System of Science, Technology, and Enterprise (SIV)
Sweden	Investing overseas Partnering public and private entities Supporting innovation in procurement policies	2 1 4	Medical Valley Huawei ZTE
Switzerland	Investing overseas Promoting service industries Developing and balancing human resources in PROs	2 2 1	N/A
United Kingdom	Promoting service industries Coordinating, funding, and evaluating PROs	2 1	Digital media and creative industries MG Rover Group
United States	Using ICT as a springboard for innovation Fostering entrepreneurship Coordinating, funding, and evaluating PROs Patenting and licensing Developing spin-off technologies Supporting innovation in procurement policies Taking advantage of dual-use technologies	4 1 2 1 2 4 4	SBIR/STTR Biotechnology and life sciences' businesses Glanz Group Haier Huawei Konka Philips Semiconductors IBM, PC Division
Most OECD Countries	Supporting innovation programs and projects Financing SMEs Creating innovation networks and clusters for SMEs	4 2 4	N/A

Source: Organisation for Economic Co-operation and Development (OECD), "China: A Synthesis Report" (report, OECD Reviews of Innovation Policy, OECD and the Ministry of Science and Technology, Beijing, China, 2007), 13, 47 (Box 3.2, Table 1.4, Table 1.5).

CONCLUSION

In general, analysts are optimistic regarding China's use of S&T to maintain a stable economic system over the long term. However, sustainable development depends on resolving inefficiencies. China's current hierarchical strategy dampens market pressures, reducing competitiveness. Whereas China's key strength is ICT development, its weakness is a lack of attention to intellectual property rights and private-sector development. In addition, because the state controls bank lending rather than permitting the market to drive lending, government procurement and bidding are open only to SOEs, excluding the development of entrepreneurial SMEs. Moreover, to determine the success of current R&D programs created under the 863 Program and to allocate funds to the most promising projects in the future, China will need to undergo another major paradigm shift, directing resources toward project evaluation.¹⁹⁶

Since the late 1980s, China has continuously increased its dependency on foreign technology. China's strategy at that time was to entice MNCs to invest in the country in exchange for access to its huge consumer market in addition to legitimately or illegitimately building on other countries' innovations. The result, according to experts, has been to make China a major manufacturing center and a rapid increase in high-technology exports. However, this strategy has "run its course," and Chinese policy makers are realizing that, in order to meet its needs in energy, water and resource utilization, environmental protection, health, and building a healthy society, China must shift to building its domestic innovative capacity.¹⁹⁷

In the military sphere, China has proven itself strong in nuclear, space, and military modernization, which has been built on a basis of dual-use technologies that can be utilized for "peaceful purposes or in 21st-century high-technology warfare," as Cao, Suttmeier, and Simon have put it. However, dual-use technologies are subject to export restrictions, making foreign suppliers an unreliable source of critical, state-of-the-art technologies. "Again, the need for indigenous innovation seems self-evident," posit Cao, Suttmeier, and Simon.¹⁹⁸

For the near future, the MLP will be the driving force behind not only China's technological but also its economic growth. The MLP also puts China in the position of having to find an acceptable balance between indigenous efforts to develop its technological base and

¹⁹⁶ OECD, "China: A Synthesis Report," 55 (Figure 3.3); "Defence Production and R&D," *Jane's Sentinel Security Assessment*; and Suttmeier, Cao, and Simon, "Knowledge Innovation," 59.

¹⁹⁷ Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan."

¹⁹⁸ Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan."

engagement with the outside world. In the early 2000s, China increased its expenditure on R&D. However, until China adopted the MLP, foreign investment and the technological achievements of other countries provided the basis for most of the country's technological growth. The MLP, therefore, marks a shift in the leadership's strategy toward indigenous innovation. The MLP calls for investing 2.5 percent of GDP, which is growing at a rate of around 10 percent per year, into R&D by the year 2020 and increasing the economic contribution of indigenous technological growth to more than 60 percent, reducing China's dependence on imported technology to no more than 30 percent.¹⁹⁹

The major factors stunting such high ambitions consist of overinvestment, inefficient use of resources, and ecological devastation. What is needed, according to China technology experts Cao, Suttmeier, and Simon, is "greater market discipline and integrity, less government corruption, and greater administrative accountability." Already, they assert, China is starting to "take seriously the notion of technological innovation as a complex, systemic problem."²⁰⁰

¹⁹⁹ Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan."

²⁰⁰ Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan."

APPENDIX A

China's High-Technology Parks as of 2004		
Park Name	Municipality/Province	Year Established
Anshan	Liaoning	1993
Baoding	Hebei	1993
Baoji	Shaanxi	1993
Baotou	Neimenggu	1993
Changchun	Jilin	1991
Changsha	Hunan	1991
Changzhou	Jiangsu	1993
Chengdu	Sichuan	1991
Chongqing	Chongqing	1991
Dalian	Liaoning	1991
Daqing	Heilongjiang	1993
Foshan	Guangdong	1993
Fuzhou	Fujian	1991
Guangzhou	Guangdong	1991
Guilin	Guanxi	1991
Guiyang	Guizhou	1993
Haerbin	Heilongjiang	1991
Hainan	Hainan	1991
Hangzhou	Zhejiang	1991
Hefei	Anhui	1991
Huizhou	Guangdong	1993
Jilin	Jilin	1993
Jinan	Shandong	1991
Kunming	Yunnan	1993
Lanzhou	Gansu	1993
Luoyang	Henan	1993
Mianyang	Sichuan	1993
Nanchang	Jiangxi	1993
Nanjing	Jiangsu	1991
Nanning	Guanxi	1993
Qingdao	Shandong	1993
Shanghai	Shanghai	1991
Shenyang	Liaoning	1991
Shenzhen	Guangdong	1991
Shijiazhuang	Hebei	1991
Suzhou	Jiangsu	1993
Taiyuan	Shanxi	1993
Tianjin	Tianjin	1991
Urumqi	Xinjiang	1993
Weifang	Shandong	1993

China's High-Technology Parks as of 2004		
Park Name	Municipality/Province	Year Established
Weihai	Shandong	1991
Wuhan Donghu	Hubei	1993
Wuxi	Jiangsu	1993
Xi'an	Shaanxi	1991
Xiamen	Fujian	1991
Xiangfan	Hubei	1993
Yangling	Shaanxi	1997
Zhengzhou	Henan	1991
Zhongguancun	Beijing	1988
Zhongshan	Guangdong	1991
Zhuhai	Guangdong	1993
Zhuzhou	Hunan	1993
Zibo	Shandong	1993
Source: Cong Cao, "Zhongguancun and China's High-tech Parks in Transition," <i>Asian Survey</i> 44, no. 5 (September–October 2004): 648.		

APPENDIX B

Translation
Outline: Medium and Long Range National Plan for Scientific and
Technical Development (2006-2020), State Council, People's Republic of
China²⁰¹

Table of Contents

- I. Preface
- II. Guidelines, Development Goals, and Overall Arrangement
 - 1. Guidelines
 - 2. Development Goals
 - 3. Overall Arrangement
- III. Key Areas and Their Priority Subjects
 - 1. Energy
 - (1) Industrial Energy Conservation
 - (2) Coal: Clean High-Efficiency Exploitation and Use, Liquefaction, and Multiple Link Output I
 - (3) Oil and Gas: Prospecting, Exploitation, and Use of Complex Geology Oil and Gas Resources
 - (4) Low-Cost Exploitation and Use of Renewable Energy Sources
 - (5) Safe Provision of Super Scale Power Transmission and Distribution and Electrical Networks
 - 2. Water and Mineral Resources
 - (6) Prioritized Allotment and Comprehensive Exploitation and Use of Water Resources
 - (7) Overall Water Conservation
 - (8) Seawater Desalinization
 - (9) Exploration and Increased Storage of Resources
 - (10) High-Efficiency Exploitation and Use of Mineral Resources
 - (11) High-Efficiency Exploitation and Use of Ocean Resources
 - (12) Overall Resource Division
 - 3. Environment
 - (13) Comprehensive Use of Sewage Treatment and Waste Material Recycling
 - (14) Restoring and Rebuilding Ecologically Weak Areas of Ecological Systems
 - (15) Oceanic Ecological and Environmental Protection
 - (16) Monitoring and Countering Global Environmental Change
 - 4. Agriculture
 - (17) Excavation, Preservation, and Creation of Germ Plasma Resources and Directional Cultivation of New Varieties

²⁰¹ People's Republic of China, "Outline: Medium and Long Range National Plan for Scientific and Technical Development," Beijing, Xinhua News Agency, February 9, 2006, http://www.gov.cn/jrzg/2006-02/09/content_183787.htm.

- (18) Healthy Aquaculture and Prevention of Epidemics in Domestic Animals and Birds
- (19) Extensive Processing and Modern Storage and Transporting of Agricultural Products
- (20) Comprehensive Exploitation and Use of Agricultural and Forestry Products
- (21) Ecological Safety of Agriculture and Forestry and Modern Forestry
- (22) Environmentally Safe Fertilizers, Formulation of Pesticides, and Ecological Agriculture
- (23) Multifunctional Agricultural Equipment and Facilities
- (24) Refined Standards and Computerization of Agricultural Operations
- (25) Modern Dairy Farming
- 5. Manufacturing
 - (26) Basic Components and Commonly Used Parts
 - (27) Digitized and Intelligent Design and Manufacturing
 - (28) Green and Automated Process Industry and Equipment
 - (29) Recyclable Steel Process Techniques and Equipment
 - (30) Large-Scale Ocean Engineering Technology and Equipment
 - (31) Basic Raw Materials
 - (32) New Generation Information Function Materials and Devices
 - (33) Key Ordnance-Related Materials and Engineering
- 6. Traffic and Transportation Industry
 - (34) Building and Maintenance of Technology and Equipment for Traffic and Transportation Infrastructure
 - (35) High-Speed Rail Traffic System
 - (36) Low-Energy Consumption and New-Energy Source Automobiles
 - (37) High-Efficiency Transportation Technology and Equipment
 - (38) Intelligent Traffic Management Systems
 - (39) Traffic and Transportation Safety and Emergency Safeguards
- 7. Information Industry and Modern Service Industry
 - (40) Modern Service Industry Information Support Technology and Large-Scale Application Software
 - (41) Next-Generation Key Network Technology and Services
 - (42) High-Performance Dependable Computers
 - (43) Sensor Networks and Intelligent Information Processing
 - (44) Digital Media Content Platforms
 - (45) High-Definition Large-Screen Flat-Panel Displays
 - (46) Core Oriented Application Information Security
- 8. Population and Health
 - (47) Safe Birth Control and Birth Defect Prevention
 - (48) Prevention of Such Serious Non-Contagious Diseases as Cardiovascular Diseases and Tumors
 - (49) Prevention of Diseases Frequently Occurring in Urban and Rural Areas
 - (50) Traditions and Innovative Developments in Chinese Medicine
 - (51) Advanced Medical Equipment and Biomedical Materials
- 9. Urbanization and Urban Development
 - (52) Urban Area Planning and Dynamic Monitoring

- (53) Improvement of Urban Functions and Economic Use of Space
- (54) Energy Saving Construction and Green Construction
- (55) Assuring a Quality Ecological Urban Living Environment
- (56) Urban Information Platforms
- 10. Public Safety
 - (57) National Public Safety Emergency Information Platform
 - (58) Early Warning and Rescue from Major Production Accidents
 - (59) Food Safety and Entry and Exit Inspection and Quarantine
 - (60) Guarding Against and Rapid Handling of Sudden Public Incidents
 - (61) Assuring Biological Safety
 - (62) Monitoring and Defense Against Major Natural Disasters
- 11. Defense
- IV. Major Specialties
- V. Leading Edge Technologies
 - 1. Biological Technology
 - (1) Target Discovery Technology
 - (2) Design Technology for Animal and Plant Varieties and Pharmaceutical Molecules
 - (3) Genetic Manipulation and Protein Engineering Technologies
 - (4) Human Body Organization Engineering Technology Based on Stem Cells
 - (5) New Generation of Industrial Biological Technology
 - 2. Information Technology
 - (6) Intelligent Perception Technology
 - (7) Self-Organized Network Technology
 - (8) Virtual Reality Technology
 - 3. New Materials Technology
 - (9) Intelligent Material and Structure Technology
 - (10) High-Temperature Superconductor Technology
 - (11) High-Performance Raw and Processed Material Technology
 - 4. Advanced Manufacturing Technology
 - (12) Extreme Manufacturing Technology
 - (13) Intelligent Service Robots
 - (14) Technology for Predicting the Life of Major Products and Major Facilities
 - 5. Advanced Energy Resource Technology
 - (15) Hydrogen Energy and Fuel Cell Technology
 - (16) Distributed Energy Supply Technology
 - (17) Fast Neutron Stacking Technology
 - (18) Magnetically Confined Nuclear Fusion
 - 6. Oceanic Technology
 - (19) Technology for Three-Dimensional Monitoring of the Ocean Environment
 - (20) Technology for Rapid Survey of Multiple Parameters of the Ocean Bottom
 - (21) Developing Natural Gas Hydrate Technology
 - (22) Deep-Sea Operation Technology
 - 7. Laser Technology
 - 8. Air and Space Technology
- VI. Basic Research

1. Scientific Development
 - (1) Basic Science
 - (2) Cross Science and New Science
2. Leading Edge Scientific Issues
 - (1) Research to Quantify Life Processes and System Integration
 - (2) Condensed State Matter and New Effects
 - (3) Deep Level Structure of Matter and Laws of Large Scale Cosmic Physics
 - (4) Nuclear Mathematics and Its Cross Area Application
 - (5) Global System Processes and Their Effect on Resources, Environment, and Disasters
 - (6) Creation of New Materials and Transforming Chemical Processes
 - (7) Brain Science and Cognitive Science
 - (8) Innovations in Scientific Experimentation and Observation Methods, Technology, and Equipment
3. Basic Research Geared Toward Major National Strategic Requirements
 - (1) Biological Basis of Human Health and Diseases
 - (2) Improvements in Agricultural Biological Heredity and Scientific Problems in the Sustainable Development of Agriculture
 - (3) Mechanism for the Affects of Human Activity on Global Systems
 - (4) Global Changes and Regional Responses
 - (5) Complex Systems and the Formation of Catastrophes and Their Prediction and Control
 - (6) Key Scientific Problems in the Sustainable Development of Energy Resources
 - (7) New Principles and New Methods in the Design and Preparation of Materials
 - (8) Scientific Basis for Manufacturing Under Extreme Environmental Conditions
 - (9) Major Aerospace Physics Problems
 - (10) Scientific Basis for Supporting the Development of Information Technology
4. Major Scientific Research Programs
 - (1) Protein Research
 - (2) Quantum Regulation and Control Research
 - (3) Nanometer Research
 - (4) Growth and Reproduction Research
- VII. Reform of Scientific and Technical Systems and Development of Innovative National Systems
 1. Support and Encourage Enterprises to Become the Mainstay of Technical Innovation
 2. Intensify the Reform of Scientific Research Organizations and Establish a Modern System of Scientific Research Institutes
 3. Promote Reform of the Science and Technology Management System
 4. Thoroughly Promote the Establishment of a National Innovation System with Chinese Characteristics
- VIII. Some Important Policies and Measures
 1. Implement Financial and Tax Policies That Encourage Enterprise Technical Innovations

2. Strengthen the Digestion, Absorption, and Further Innovation of Imported Technology
 3. Implement Government Purchases That Promote Independent Initiative
 4. Implement an Intellectual Property Rights Strategy and a Technical Standards Strategy
 5. Implement a Monetary Policy That Promotes Innovative Business Undertakings
 6. Accelerate New High Technology Industrialization and Popularize Advanced Applied Technology
 7. Perfect Mechanisms for Combining the Military with the Civilian and Using the Military in the Civilian [sector]
 8. Expand International and Regional Scientific and Technical Cooperation and Exchanges
 9. Improve the Scientific and Cultural Quality of All Nationalities [Ethnic Groups] and Build Social Environments Conducive to Scientific and Technical Innovation
- IX. Investment in Science and Technology and Platforms with Basic Scientific and Technical Conditions
1. Establish a Multi-Component, Multi-Channel Science and Technology Investment System
 2. Adjust and Prioritize the Investment Structure and Improve the Useful Benefits of Scientific and Technical Expenditures
 3. Accelerate the Establishment of Platforms with Basic Scientific and Technical Conditions
 4. Establish Mechanisms for Sharing Platforms with Basic Scientific and Technical Conditions
- X. Establish a Talent Force
1. Accelerate the Education and Training of a Group of High-Level Specialists at Leading-Edge World Levels
 2. Make Full Use of Education in Important Activities to Train Innovative Talent
 3. Support Enterprises in Training and Absorbing Scientific and Technical Talent
 4. Strengthen Efforts to Absorb High-Level Overseas Students and Foreign Talent
 5. Form a Cultural Environment Conducive to Growing Innovative Talent

The 16th Party Congress, starting from the overall situation of totally establishing a comfortable society and accelerating the promotion of Socialist modernization, requires the formulation of a national plan for long-range development of science and technology. Accordingly, the State Council has formulated this outline.

Translated by:
Ronald Dolan
Federal Research Division
Library of Congress
August 2007

APPENDIX C

Priority Topics, Areas, and Programs Identified in China's MLP

Strategic Research

- Agricultural science and technology
- Basic science
- Conditions, platforms, and infrastructures for S&T development
- Culture for innovation and S&T popularization
- Ecology, environmental protection, and recycled economy S&T
- Energy, resources, and ocean S&T
- Human resources for S&T
- Input and management model S&T
- Law and policies for S&T development
- Modern manufacturing development S&T
- Modern services industry S&T
- National defense S&T
- Overall strategy for medium- to long-term S&T development
- Population and health S&T
- Public security S&T
- Regional innovation system
- S&T system reform and national innovation system
- Strategic high technology and industrialization of high and new technology
- Transportation S&T
- Urban development and urbanization S&T

Key Areas

- Agriculture
- Energy
- Environment
- Information technology industry and modern services
- Manufacturing
- National defense
- Population and health
- Public securities
- Transportation
- Urbanization and urban development
- Water and mineral resources

Frontier Technologies

- Advanced energy
- Advanced manufacturing
- Aerospace and aeronautics
- Biotechnology

- Information
- Laser
- New materials
- Ocean

Engineering Megaprojects

- Advanced numeric-controlled machinery and basic manufacturing technology
- Control and treatment of AIDS, hepatitis, and other major diseases
- Core electronic components, high-end generic chips, and basic software
- Drug innovation and development
- Extra large scale integrated circuit manufacturing and technique
- Genetically modified new-organism variety breeding
- High-definition Earth observation systems
- Large advanced nuclear reactors
- Large aircraft
- Large-scale oil and gas exploration
- Manned aerospace and Moon exploration
- New-generation broadband wireless mobile telecommunications
- Water pollution control and treatment

Science Megaprojects

- Development and reproductive biology
- Nanotechnology
- Protein science
- Quantum research

Source: Cong Cao, Richard P. Suttmeier, and Denis Fred Simon. "China's 15-Year Science and Technology Plan." *Physics Today* 59, no. 12 (December 2006): 38, 43.
<http://www.physicstoday.org/>.

APPENDIX D

Calculating China's Defence Expenditure

The 2006 Official Defence Budget

In recent years there has been much discussion about the true level of China's total defence expenditure, not least following the publication, in July 2005, of the US Department of Defense annual report to Congress, 'The Military Power of the People's Republic of China', which suggested that China's military spending in 2005 was two to three times higher than the Official Budget of RMB244bn (\$29.8bn). Although it is still not possible to calculate with complete certainty total military related expenditures in the PRC, changes in China's defence budgeting system and new research using Chinese language documents have prompted *The Military Balance* to set out its current methodology for calculating total defence expenditure in China and to highlight some of the problems that remain in this endeavour.

In 2006, China's publicly disclosed defence budget rose to RMB280bn, up from RMB244bn in 2005, marking the 15th year that the official defence budget has grown by over 10%. Once adjusted for inflation, the Official Budget has now grown, in real terms, by 96% since 2000 and by 300% during the past decade.

Until 1998, when China released its first 'White Paper on China's National Defence', little was known about the People's Liberation Army (PLA) budget save for a single aggregate line item in the Central Government Budget. Since then further White Papers have been published in 2000, 2002 and 2004 and although financial details are sparse, the documents have contained a simple breakdown of the defence budget by broad spending category: Personnel; Operations and Equipment. The 2004 edition of the White Paper highlighted the following five reasons for the strong upward trend in the Official Defence Budget in recent years:

1. Increases in salaries and allowances for military personnel in order to match the socio-economic development and per-capita income rise of both urban and rural residents. Following on from the unified wage adjustment policy for all personnel of state bodies, the salaries and living expenses of military personnel have been increased several times.
2. The introduction of a social security system for military personnel, including disability and life insurance, housing subsidies,

medical insurance for demobilised servicemen and the extension of certain benefits to the spouses of servicemen.

3. Funds for the structural and organisational reform of the military, including the expenses incurred as the PLA continues with the process of downsizing.
4. Increasing investment in 'high-calibre talent' within the armed forces, including improvements to military educational facilities in line with the PLA's 'Strategic Project for Talented People'.
5. Moderate increase in equipment procurement aimed at 'promoting the leapfrog development of weaponry'.

Not only has China's Official Defence Budget increased substantially in absolute terms, it has also risen relative to the size of the Chinese economy, from 1.08% of GDP in 1995 to 1.55% of GDP in 2005 (Table X), although, as Chinese officials point out this is still lower than the US (3.9% in 2005), South Korea (2.5% in 2005) and most major NATO countries. In line with the significant annual funding increase, changes made to the defence budget process, together with the publication of bi-annual White Papers, have helped to improve transparency of the PLA's finances. In the past, the PLA was the recipient of revenues such as commercial earnings, in-kind subsidies and revenue-sharing practices in addition to the allocation from the Central Government Budget. As a result the official budget was something of an arbitrary figure, but a series of budget reforms since 1998 have helped to lessen the discrepancy between the PLA's Official Budget and its actual total revenue. That said, there are still several major defence expenditure items that would commonly be included in the defence budgets of Western nations that remain outside the Official Defence Budget and these are addressed below.

**Table 34 China Defence Budget
Official Breakdown White Paper, 2002 &
2004 (RMBm)**

Year	Personnel	Operations	Equipment	Total
2000	40,550	41,274	38,930	120,754
2001	46,163	48,581	49,460	144,204
2002	54,043	58,123	57,278	169,444
2003	62,005	64,104	64,486	190,787

The most significant change to affect the PLA's finances in recent years was the 1998 order banning the military from continuing its business activities, a practice which had been responsible for generating significant additional revenue throughout the armed forces. Although it is unclear how many PLA-owned businesses have actually been divested since then, it is intended that ultimately the PLA will retain only its farming interests. Other significant reforms include the introduction in the early 1990s of regular accounting and auditing procedures, making it more difficult for military units to hide their assets and profits and the creation in 1998 of the General Armaments Division to oversee the introduction of a market-based procurement bidding system. And in 2001, a radical zero-based budgeting initiative was introduced to several ministries, including defence. Under this system, all military units are obliged to calculate their anticipated requirement for the coming year from zero, rather than taking the current year's budget and simply adding an additional percentage as had been the case under the previous system.

However, while the Official Budget has become more transparent and is a useful tool for measuring the general trend in Chinese defence expenditure, it is less helpful when making comparisons with other

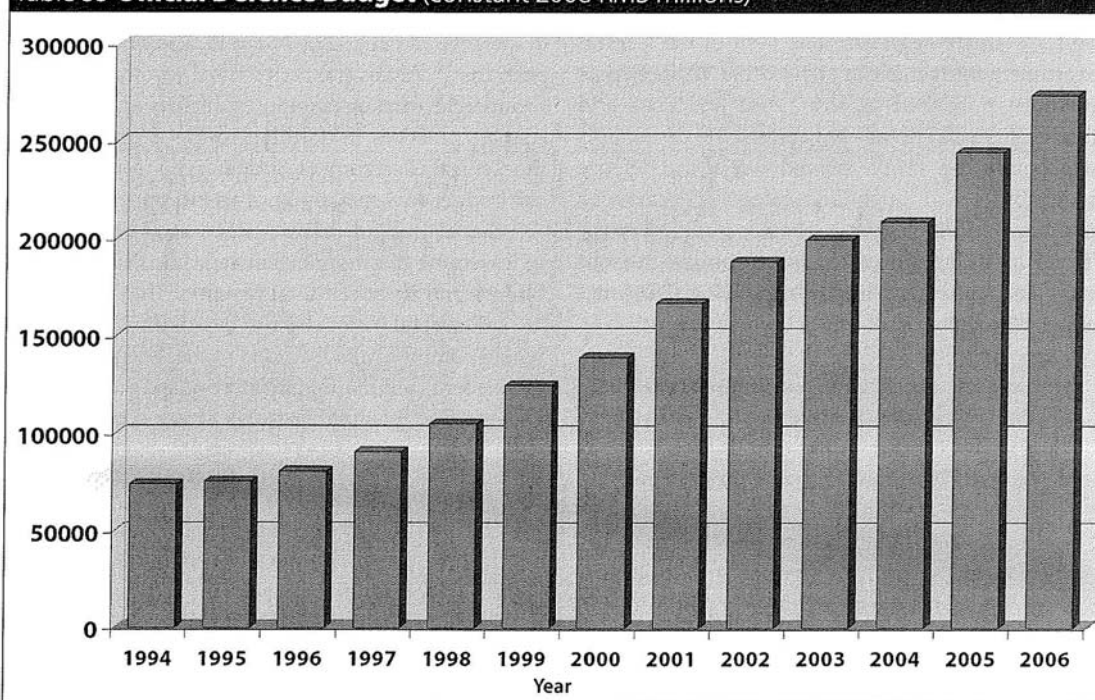
countries for two principle reasons. First, few analysts outside the PRC consider the Official Chinese Defence Budget to include all military-related expenditures and second, is the problem of exchange rates.

Exchange rates

At the official market exchange rate, the 2003 Chinese Defence Budget measured \$23.0bn. However, because the official market exchange rate between the currencies of developing and developed countries is often distorted, economists often use a different approach when comparing economic data between the two. By assessing the cost of purchasing a common basket of goods and services in one country with its cost in another, economists derive an alternative exchange rate known as purchasing power parity (PPP). For example, China's GDP in 2003 measured RMB12,151bn, \$1,467bn if converted at official exchange rates; however, using its own PPP rate, the World Bank calculated that, in 2003, Chinese GDP was the equivalent of US\$6,435bn. If the same methodology were applied directly to Chinese defence budget data, then the official budget for 2003 would quadruple from \$23.0bn to \$101.4bn.

However, whereas PPP is helpful when comparing certain types of macro-economic data between coun-

Table 35 Official Defence Budget (constant 2006 RMB millions)



tries, such as aggregate GDP or per-capita income, it would be misleading to use a straightforward PPP approach to headline military spending. Military budgets are comprised of a broad range of diverse expenditure items not all of which are suited to a simple PPP conversion. In the case of China, adopting a PPP approach may be appropriate where personnel costs, food, housing and other basic operational expenses are concerned, because these costs are substantially lower than in the West. Meanwhile, other expenditure items such as procurement might not be accurately measured by PPP, particularly items and components bought on world markets and thus subject to international market exchange rates. One solution to this problem is the use of different rates for different expenditures – PPP rates when measuring personnel costs and market exchange rates where the purchase and development of military equipment is concerned.

However, acknowledging that a PPP methodology is more appropriate for certain military-related expenditures does not solve the problem; there is also a significant question over which PPP rate to use. As yet, there exists no explicit military PPP data series and, given that a typical basket of Chinese goods, heavily weighted towards food, low-cost clothing and other basic commodities which are relatively

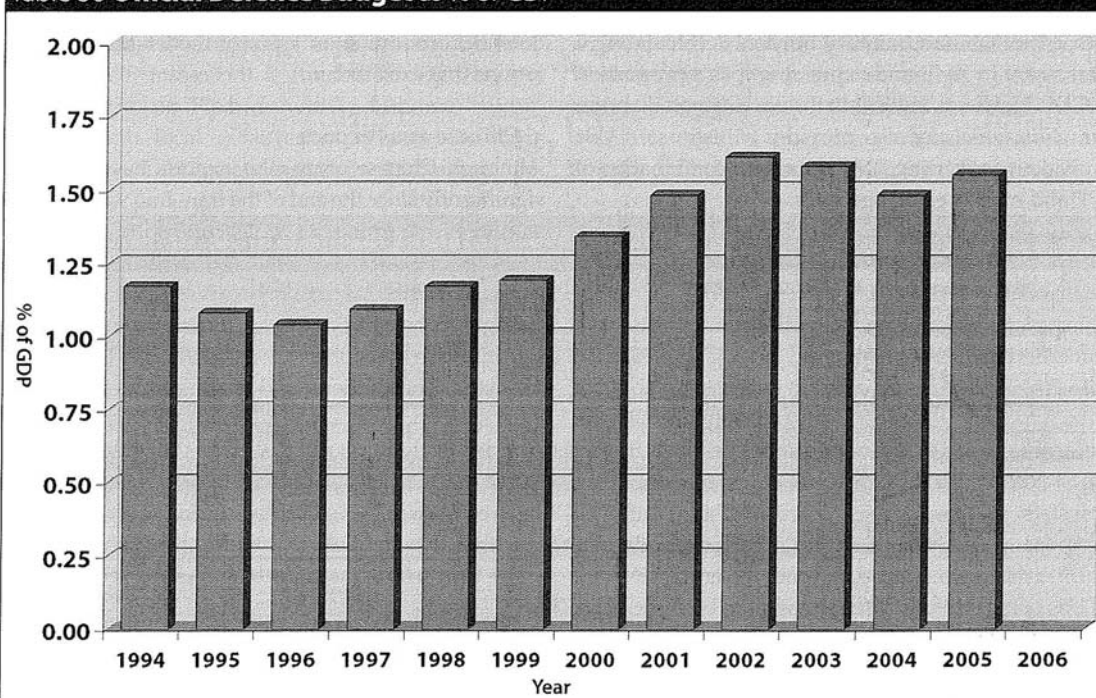
cheap is rather different to a typical basket of US goods and services consisting of more expensive technology products, holidays and mortgages, the use of a general PPP rate is hardly ideal. Even so, in the absence of an explicit military PPP and despite these weaknesses, where conversions of RMB data into US\$ are calculated using PPP, *The Military Balance* adopts the World Bank rate referred to above.

It should be noted that while use of a PPP rate is advisable when analysing Chinese defence spending data, the choice of PPP RMB/US\$ rate used can have a significant impact on the final figures obtained and as such is one of the reasons why Western estimates of Chinese defence spending vary so widely.

Defence expenditure transparency

Compounding the problem of exchange rates is the lack of transparency and detail available about military-related expenditures outside of the Official Defence Budget. As noted, defence White Papers published since 1998 have included a breakdown of the official budget into three expenditure categories: personnel, operations and equipment (Table 34). And, although other internal documents add some additional detail to these broad categories, the Official Budget clearly excludes other military-related expenditures.

Table 36 Official Defence Budget as % of GDP



As noted in previous editions of *The Military Balance*, most analysts agree that the following major military accounting items, commonly included in Western budgets, are absent from the official Chinese defence budget:

- Procurement of weapons from abroad
- State subsidies to the defence industry
- Some research and development (R&D) programmes
- Funding of paramilitaries

Analysts have also suggested that a proportion of centrally funded construction programmes should be included in total defence expenditure calculations as well as subsidies to demobilised personnel which are funded by the Ministry of Civil Affairs. However, due to the difficulty in estimating these expenditures, the IISS excludes them from its own calculation of China's total military expenditure.

Due to the difficulty in obtaining accurate expenditure figures on the major non-transparent items listed above, the IISS adopts a top-down approach, calculating the size of total Chinese military-related expenditure from estimates of the various revenues allocated to the military, over and above the Official Defence Budget. Due to the problems associated with exchange rates, the safest way of expressing the results of this analysis and arriving at a measurement of China's 'military burden' is calculating a total figure in RMB and expressing it as a proportion of GDP. However, subject to the caveats noted above, *The Military Balance* also provides an estimated US\$ equivalent converting RMB data via a combination of PPP and market exchange rates.

Additional Chinese military revenue

1. Overseas weapons procurement

China meets most of its weapons requirements from domestic production. However, during the past ten years, the PLA has purchased an increasing amount of foreign military equipment, most notably from Russia. According to the 2004 Congressional Research Service (CRS) Report for Congress on 'Conventional Arms Transfers to Developing Nations', China imported weapons systems valued at US\$1.0bn in 2004 and a total of US\$13bn between 1997 and 2004, an annual average of US\$1.6bn. In recent years, Russia has been the major supplier of new weapons systems to the PLA, delivering Su-27 and Su-30 MKK fighter aircraft to the air force and *Sovremenny*-class destroyers and *Kilo*-class subma-

ines to the navy. Although the exact payment terms and schedules for these acquisitions is not known, it is believed that major overseas procurement is funded by extra-budgetary funds reportedly drawn from specially arranged hard-currency accounts controlled by the State Council rather than the Chinese military.

2. Defence industry subsidies

Since the early 1980s China's defence sector has been in serious decline owing to the steady fall in procurement orders. As a result, the defence industry has undergone a massive conversion process such that nearly 70% of the output of military factories is now accounted for by the production of civilian goods. China's State Budget does provide a figure for subsidies that the central government allocates to 'loss-making enterprises' (LME), which in 2003 amounted to RMB22.6bn. Since it is highly likely that the conversion process has had variable success, many of these factories will receive considerable subsidies, possibly accounting for 25% of the total allocation of LME subsidies by central government.

In addition to subsidies allocated to LME, analysts also believe that the State Council pays large subsidies to defence companies or those factories that produce goods partially for the military but are administered under one of the ten State Council corporations. Although these budgets are not made public, David Shambaugh suggests that direct allocations to the defence industry could easily amount to \$500m per defence corporation, or \$5bn for the ten major corporations that exist today.

3. Chinese arms exports

Although Chinese arms-sales exports have declined significantly since the end of the Iran-Iraq war, the CRS calculates that China has achieved exports amounting to \$5.5bn between 1997 and 2004, an annual average of nearly \$700m. While a proportion of this revenue is thought to benefit the PLA, Chinese defence exports fall into two categories, those conducted by defence industrial corporations and those conducted by the PLA itself and it is only funds from the latter category that are likely to boost PLA coffers directly. In recent years the majority of China's weapons exports have been conducted by defence industrial corporations and it is therefore unlikely that the PLA has received any more than 50% of the value of annual arms exports.

4. R&D

The amount of funding that is channeled into military-related research and development is one

of the hardest areas of additional military-related expenditures to determine, not least because there appear to be several different revenue sources: the General Armaments Division; the Commission of Science Technology and Industry for National Defence (COSTIND); the Ministry of State Science and Technology and the defence industries themselves. An estimation of the level of state funding of defence RDT&E can be obtained. According to Shaoguang Wang, RDT&E is financed from two sources: the general R&D fund and the 'new product promotion fund', data on which can be obtained from the annual publication *China Statistical Yearbook*, compiled by the National Bureau of Statistics of China. In 2003, the general R&D fund, which includes basic and applied research as well as experimental development, amounted to RMB154bn whilst government funding of science and technology, including 'new product development, expenditure for intermediate trial and subsidies for important scientific research', amounted to RMB84bn. Wang suggests that the majority of this funding is for civilian purposes but that 15% of the general R&D fund and 35% of the S&T budget should be included in a notional budget of total Chinese military-related spending.

5. People's Armed Police (PAP)

Funding for paramilitary organisations, like the PAP, is another item that does not appear in the Defence Budget itself. Instead, it is funded largely through the Ministry of Finance with additional contributions from local government sources. In 2003, central government spending on the PAP amounted

to RMB23.9bn with a smaller allocation from local government sources of RMB2.4bn.

6. Local militia

The militia is a backup force of the PLA and PAP, which is expected to help maintain social order, to participate in emergency rescue and disaster relief and to provide combat support for the PLA when war breaks out. The procurement element of the militia's budget is contained in the Official Defence Budget, however, operating expenses are funded by local government. In 2003, this amounted to RMB2.2bn.

Summary

The results detailed in Table 37 indicate that total military-related revenue accruing to the PLA in 2003 could have amounted to as much as RMB328.4bn, about 1.7 times the official defence budget of RMB190.7bn. As previously noted, due to the problems with exchange rates, the best use of these data as a basis for international comparison is to calculate the total as a proportion of national income. Using this methodology, we estimate that total Chinese defence expenditure was 2.7% of GDP in 2003, which compares to 3.7% in the US, 2.4% in South Korea, 2.4% in the UK and 1% in Japan.

Converted into US dollars at the prevailing exchange rate, China's total 2003 defence expenditure equals \$39.6bn. However, if personnel costs together with expenditure on the PAP are converted using the World Bank's PPP rate, then the budget in US\$ terms jumps to \$75.5bn which illustrates the sensitivity of the figures to different exchange rates and the caution that should be adopted if opting for this approach.

Table 37 Estimated Total Military-related Revenue 2003

RMB bn		US\$ bn at market exchange rates	US\$ bn incl PPP estimates ^a
Official PLA budget (including local militia funding)	190.7	23.0	48.4 ^a
Foreign weapons purchases (1997–2004 average)	13.2	1.6	1.6
Subsidies			
- Loss making enterprises	5.6	0.67	0.67
- Defence Industry	41.4	5.00	5.00
R&D	23.1	2.78	2.78
New Product Expenditure	25.2	3.04	3.04
Arms exports (50% of annual average)	2.9	0.35	0.35
PAP			
- Central	23.9	2.9	12.7 ^a
- Local	2.4	0.28	1.27 ^a
Total	328.4	39.6	75.5
% of GDP	2.7	2.7	n.a.

^a Includes PPP estimates

Source: International Institute for Strategic Studies, *The Military Balance* (London: Routledge, 2006), 249–53.

BIBLIOGRAPHY

- Applebaum, Richard P. "CNS Voices: Rich Appelbaum on Nanotechnology Research in China." Interview by Center for Nanotechnology in Society, University of California, Santa Barbara, September 14, 2006. <http://www.cns.ucsb.edu/>.
- Appelbaum, Richard P., and Rachel A. Parker. "Innovation, Collaboration, and Top-Down Policy: China's Bid to Become a Global Leader in Nanotechnology." Draft Paper, University of California at Santa Barbara, September 21, 2007. Cited with the permission of the authors.
- Appelbaum, Richard P., and Rachel A. Parker. "Nanotechnology in a Global Context: The Case of China." Paper presented at Nanotechnology and the Emerging Global Economy, Duke University Center on Globalization, Governance, and Competitiveness, Durham, North Carolina, March 29–30, 2007. <http://www.cggc.duke.edu/>.
- Banks, Arthur S., Thomas C. Muller, and William R. Overstreet, eds. *Political Handbook of the World 2007*. Washington, DC: Congressional Quarterly, 2007.
- Baum, Richard, ed. *China's Four Modernizations: The New Technological Revolution*. Boulder, Colorado: Westview Press, 1980.
- "China: Report on PRC Military, S&T Developments 1–15 Jan 08." Report, Department of Defense, Washington, DC, February 11, 2008. <https://www.opensource.gov/> (OSC document no. CPP20080212478002; accessed February 14, 2008).
- China's Environment Series*, no. 9. Washington, DC: Woodrow Wilson International Center for Scholars, 2007. <http://www.wilsoncenter.org/topics/pubs/ces9.pdf>.
- China's New Great Leap Forward: High Technology and Military Power in the Next Half-Century*. Washington, DC: Hudson Institute, 2005.
- Christoff, Peggy Spitzer. "Relations between the United States and the People's Republic of China in the Modernization of Science and Technology in China." PhD diss., American University, 1984.
- Cao, Cong. "Challenges for Technological Development in China's Industry: Foreign Investors are the Main Providers of Technology." *China Perspectives*, no. 54 (July–August 2004).
- Cao, Cong. "Chinese Science and the Nobel Prize Complex." *Minerva* 42 (2004): 151–72.
- Cao, Cong. "New Key Players in the Global System of Science, Technology, and Education." Preliminary Report, Levin Graduate Institute of International Relations and Commerce, State University of New York, 2007. Cited with the consent of the author.

- Cao, Cong. "Zhongguancun and China's High-tech Parks in Transition." *Asian Survey* 44, no. 5 (September–October 2004): 647–68.
- Cao, Cong, and Richard P. Suttmeier. "China's New Scientific Elite: Distinguished Young Scientists, the Research Environment, and Hopes for Chinese Science." *China Quarterly* 168 (December 2001): 960–84.
- Cao, Cong, Richard P. Suttmeier, and Denis Fred Simon. "China's 15-Year Science and Technology Plan." *Physics Today* 59, no. 12 (December 2006): 38–43.
<http://www.physicstoday.org/>.
- Carnegie Endowment for International Peace. New Vision Program. Debate Series: Reframing China Policy Debate 3: The Implications of China's Military Modernization. "Is China's Military Modernization Program a Growing Threat to the United States and Asia?" Washington DC, February 6, 2007. http://www.carnegieendowment.org/files/debate_3%20final%20transcript.pdf.
- Day, Kristen A., ed. *China's Environment and the Challenge of Sustainable Development*. Armonk, New York: M.E. Sharpe, 2005.
- Downs, Erica S. "The Fact and Fiction of Sino-African Energy Relations." *China Security* 3, no. 3 (Summer 2007): 42–68.
- Economy, Elizabeth C. *The River Runs Black: The Environmental Challenge to China's Future*. Ithaca, New York: Cornell University Press, 2004.
- Elman, Benjamin A. *A Cultural History of Modern Science in China*. Cambridge, Massachusetts: Harvard University Press, 2006.
- Elman, Benjamin A. *On Their Own Terms: Science in China, 1550–1900*. Cambridge, Massachusetts: Harvard University Press, 2005.
- "Executive Summary, China, Defense." *Jane's Sentinel Security Assessment – China and Northeast Asia*, May 2007 (accessed through Intelink, March 15, 2008).
- Fairley, Peter. "Part I: China's Coal Future." *Technology Review*, January 4, 2007.
<http://www.technologyreview.com/Energy/17963/>.
- Fairley, Peter. "Part II: China's Coal Future." *Technology Review*, January 5, 2007.
<http://www.technologyreview.com/Energy/17964/>.
- Federation of American Scientists. News release of translation of the People's Republic of China's refutation of the Final Report of the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China. <http://www.fas.org/sgp/news/1999/07/chinacox/index.html>.

- Ferrantino, Michael, Robert Koopman, Zhi Wang, Falan Yinug, Ling Chen, Fengjie Qu, and Haifeng Wang. "Classification and Statistical Reconciliation of Trade in Advanced Technology Products: The Case of China and the United States." Joint Working Paper on U.S.–China Trade in Advanced Technology Products, United States International Trade Commission, Tsinghua University, and National Development and Reform Commission, United States and People's Republic of China, 2006.
- Fonow, Robert C. "Beyond the Mainland: Chinese Telecommunications Expansion." *Defense Horizons*, no. 29 (July 2003): 1–8. http://www.ndu.edu/ctnsp/defense_horizons.htm.
- Frouart, Loïc. "Chinese Defence Policy in 2007." *Défense nationale et sécurité collective*, May 2007. <http://www.defnat.com/>.
- Guangzhou. *Guangdong Zaoshan* [China's Push to Become World's Top Shipbuilding Country]. March 2007, 1–3. <https://www.opensource.gov/> (OSC document no. CPP20080204465001).
- Harwit, Eric. "Building China's Telecommunications Network: Industrial Policy and the Role of Chinese State-Owned, Foreign and Private Domestic Enterprises." *China Quarterly*, no. 190 (June 2007): 311–32.
- International Institute for Strategic Studies. *The Military Balance* (London: Routledge, 2006, 2007, 2008).
- Jiang, Wenran. "CCP Celebrates 50 Years of Nuclear Achievements." *China Brief* 5, no.23 (November 8, 2005). http://www.jamestown.org/china_brief/.
- Jin, Xiaoming. "Deng Xiaoping and Sino-U.S. S&T Cooperation." *Science and Technology Daily*, August 20–21, 2004.
- Jin Xiaoming. "The China-U.S. Relationship in Science and Technology." Paper presented at conference, China's Emerging Technological Trajectory in the 21st Century, Lally School of Management and Technology, Rensselaer Polytechnic Institute, New York, September 4–6, 2003.
- Karasov, Corliss. "The Capacity to Change: Building Global Environmental Health Expertise." *Environmental Health Perspectives* 111, no. 9 (July 2003).
- Keidel, Albert. "China's Looming Crisis—Inflation Returns." Policy Brief 54, Carnegie Endowment for International Peace. Washington, DC, September 2007. http://www.carnegieendowment.org/files/pb54_keidel_china_looming_crisis_final.pdf.
- Kostoff, Ronald N., Michael B. Briggs, Robert L. Rushenberg, Christine A. Bowles, and Michael Pecht. *The Structure and Infrastructure of Chinese Science and Technology*. Arlington, Virginia: Office of Naval Research, 2006.

- Lam, Willy. "Reorienting the 17th Party Congress: Boosting Unity and Thwarting Taiwan." *China Brief* 7, no. 18 (October 3, 2007): [no page numbers]. http://www.jamestown.org/china_brief/.
- Li, Ganjie, and Ding Zhongzhi. "Analysis and Thoughts on Key Issues of China's Nuclear Power Development." *Journal of North China Electric Power University* 1 (2006).
- Ma, Junru, and Thomas J. Ratchford. "Report to the 12th (2006) Meeting of the United States (U.S.)–People's Republic of China (PRC) Joint Commission on Scientific and Technological Cooperation (JCM) on the U.S.–China Forum on Science and Technology (S&T) Policy." Beijing, October 19, 2006, 401–12.
- Medeiros, Evan S., Roger Cliff, Keith Crane, and James C. Mulvenon. *A New Direction for China's Defense Industry*. Santa Monica, California: RAND, 2005.
- Metzger, Thomas A. *Escape from Predicament: Neo-Confucianism and China's Evolving Political Culture*. New York: Columbia University Press, 1977.
- Miller, Alice Lyman. "The Road to the 17th Party Congress." *China Leadership Monitor*, no. 18 (Spring 2006): 1–8. http://media.hoover.org/documents/clm18_lm.pdf.
- Miller, Patrick M. "Non-U.S. Space Programs: China Profile and Potential Contributions to Collaborative Efforts." Report, Federal Research Division, Library of Congress, Washington, DC, February 2005.
- Organisation for Economic Co-operation and Development (OECD). "China: A Synthesis Report." Report, OECD Reviews of Innovation Policy, OECD and the Ministry of Science and Technology, Beijing, China, August 2007.
- Oxford Analytica. "National Innovation Systems of India and China." Draft Report for the National Intelligence Council, Washington, DC, November 24, 2006.
- Pei, Minxin. "Corruption Threatens China's Future." Policy Brief 55, Carnegie Endowment for International Peace, October 2007. http://www.carnegieendowment.org/files/pb55_pei_china_corruption_final.pdf.
- People's Republic of China. "China's Scientific and Technological Actions on Climate Change." Joint Report of the Ministry of Science and Technology, the National Development and Reform Commission, the Ministry of Foreign Affairs, the Ministry of Education, the Ministry of Agriculture, the State Environmental Protection Administration, the State Forestry Administration, the Chinese Academy of Sciences, the China Meteorology Administration, National Natural Science Foundation, State Oceanic Administration, and China Association for Science and Technology, Beijing, China, June 2007. <http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File199.pdf>.

- People's Republic of China. "Outline: Medium and Long Range National Plan for Scientific and Technical Development." Beijing, Xinhua News Agency, February 9, 2006. http://www.gov.cn/jrzg/2006-02/09/content_183787.htm.
- People's Republic of China. Ministry of Science and Technology. "S&T Statistics Data Book 2007." <http://www.most.gov.cn/eng/statistics/2004/index.htm>.
- Pillsbury, Michael. "China's Progress in Technological Competitiveness: The Need for a New Assessment." Research Report, U.S.–China Economic and Security Review Commission, Washington, DC, April 2005. <http://www.uscc.gov/>.
- Preeg, Ernest H. *The Emerging Chinese Advanced Technology Superstate*. Washington, DC: Manufacturers Alliance/MAPI and Hudson Institute, 2005.
- Sabathier, Vincent, and G. Ryan Faith. "Smart Power through Space." *International Space Exploration Update*, February 20, 2008. http://www.csis.org/media/isis/pubs/080220_smart_power_through_space.pdf.
- Segal, Adam. "The Civilian High-Technology Economy: Where is it Heading?" Statement at conference on Chinese Military Modernization and Export Control Regimes, U.S.–China Economic and Security Review Commission, Washington, DC, March 16, 2006. <http://www.uscc.gov/>.
- Segal, Adam. *Digital Dragon: High Technology Enterprises in China*. Ithaca, New York: Cornell University Press, 2003.
- Segal, Adam. "NO: Setting up Antimissile System Aimed at the Chinese Will Leave the United States Less Secure." *Insight Magazine*, April 16, 2002.
- Serger, Sylvia Schwaag, and Magnus Breidne. "China's Fifteen Year Plan for Science and Technology: An Assessment." *Asia Policy*, no. 4 (July 2007): 135–64. http://nbr.org/publications/asia_policy/AP4/AP4%20Serger_Breidne%20RN.pdf.
- Simon, Denis Fred. "Hearing on Chinese High Technology Development." Paper presented to the U.S.–China Economic and Security Review Commission, Stanford University, Palo Alto, California, April 21–22, 2005. <http://www.uscc.gov/>.
- Simon, Denis Fred. "The Technology Transfer Issue in Sino-U.S. Relations, 1981–2006: Some Reflections, Thoughts, and Perspectives." Paper presented at the meeting of the U.S.–China Forum on Science and Technology (S&T Policy), Beijing, October 16–17, 2006.
- Smith, Marcia S. "China's Space Program: An Overview." CRS Report for Congress, No. RS21641, Congressional Research Service, Library of Congress, Washington, DC, updated October 18, 2005. <http://www.fas.org/sgp/crs/space/RS21641.pdf>.

- Sun, Yifei. "China's National Innovation System in Transition." *Eurasian Geography and Economics* 43, no. 6 (September 2002): 476–92.
- Suttmeier, Richard P. "A New Technonationalism? China and the Development of Technical Standards." *Communications of the ACM* 48, no. 4 (April 2005): 35–37.
- Suttmeier, Richard P. "China's Techno-Warriors: Another View." Review of *Chinese Techno-Warriors: National Security and Strategic Competition from the Nuclear Age to the Information Age*, by Evan Feigenbaum. *China Quarterly* 179 (September 2004): 804–10.
- Suttmeier, Richard P. "The Next Great Leap Forward." *New Scientist*, February 10, 2007, 46–47. <http://www.newscientist.com/>.
- Suttmeier, Richard P. "Science and Technology: A New World In the Making?" In *Strategic Asia 2004–05*. Vol. 4, *Confronting Terrorism in the Pursuit of Power*, edited by Ashley Tellis and Michael Wills, 457–91. Seattle: National Bureau of Asian Research, 2004. http://www.nbr.org/publications/strategic_asia/pdf/sa04_14sci-tech.pdf.
- Suttmeier, Richard P., and Yao Xiangkui. "China's Post-WTO Technology Policy: Standards, Software, and the Changing Nature of Techno-Nationalism." NBR Special Report, National Bureau of Asian Research, Seattle and Washington, DC, May 2004. <http://www.nbr.org/publications/issue.aspx?ID=126>.
- Suttmeier, Richard P., Cong Cao, and Denis Fred Simon. "China's Innovation Challenge and the Remaking of the Chinese Academy of Sciences." *Innovations* 1, no. 3 (Summer 2006): 78–97.
- Suttmeier, Richard P., Cong Cao, and Denis Fred Simon. "Knowledge Innovation and the Chinese Academy of Sciences." *Science* 312, no. 5770 (April 7, 2006): 58–59.
- Suttmeier, Richard P., Yao Xiangkui and Alex Tan. "Standards of Power? Technology, Institutions, Politics in the Development of China's National Standards Strategy." NBR Special Report, National Bureau of Asian Research, Seattle and Washington, DC, June 2006. <http://www.nbr.org/publications/specialreport/pdf/SR10.pdf>.
- Tellis, Ashley. "China's Military Space Strategy." *Survival* 49, no. 3 (September 2007): 41–72. <http://dx.doi.org/10.1080/00396330701564752>.
- Tellis, Ashley J. "Punching the U.S. Military's 'Soft Ribs': China's Antisatellite Weapon Test in Strategic Perspective." Policy Brief 51, Carnegie Endowment for International Peace, Washington, DC, June 2007.
- United States. Congress. House. Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China. *Final Report of the Select Committee*. 106th Cong., 1st sess., January 3, 1999. <http://www.house.gov/coxreport/>.

United States. Department of Defense. Office of the Secretary of Defense. *Military Power of the People's Republic of China 2007*. Annual Report to Congress. Washington, DC, 2007.

United States. Department of Energy. Energy Information Administration. "China: Background," n.d. <http://www.eia.doe.gov/emeu/cabs/China/Background.html>.

United States. Government Accountability Office. "Border Security: Improvements Needed to Reduce Time Taken to Adjudicate Visas for Science Students and Scholars." Report GAO-04-371, Washington, DC, February 25, 2004. <http://www.gao.gov/new.items/d04371.pdf>.

United States. Government Accountability Office. "Export Controls: Better Interagency Coordination Needed on Satellite Exports." Report GAO/NSIAD-99-182, Washington, DC, September 17, 1999. <http://www.gao.gov/archive/1999/ns99182.pdf>.

United States. Government Accountability Office. "Offshoring: U.S. Semiconductor and Software Industries Increasingly Produced in China and India." Report GAO-06-423, Washington, DC, September 7, 2006. <http://www.gao.gov/new.items/d06423.pdf>.

United States. Office of Technology Assessment. "August 1996 OTA Archive." <http://www.gpo.gov/ota/>.

United States National Science Foundation. "Asia's Rising Science and Technology Strength: Comparative Indicators for Asia, the European Union, and the United States." Special Report NSF-07-319, Arlington, Virginia, August 2007. <http://www.nsf.gov/statistics/nsf07319/pdf/nsf07319.pdf>.

United States National Science Foundation. "Science and Engineering Statistics." <http://www.nsf.gov/statistics/>.

United States-China Economic and Security Review Commission. "China's Technology Development and Implications for the U.S. Defense Industrial Base." Chap. 2 in *Report to the Congress of the United States*. Washington, DC: GPO, 2005. http://www.uscc.gov/annual_report/2005/annual_report_full_05.pdf.

Walsh, Kathleen A. "China's High-Technology Development." Testimony Before the U.S.-China Economic and Security Review Commission hearings on China's High-Technology Development, Palo Alto, California, April 21, 2005, 1-10.

Walsh, Kathleen A. "Soaring Eagle, Flying Dragon: Industrial R&D and Innovation in the United States and China." Paper presented at the U.S.-China Forum on Science and Technology (S&T) Policy, Beijing, China, October 19, 2006, 215-36. http://www.uscc.gov/hearings/2005hearings/written_testimonies/05_21_22wrts/walsh_kathleen_wrts.pdf.

World Bank Group. *China: Air, Land, and Water*. Washington, DC, 2001.

Xu, Guanhua. "Minister Jiang Zemin's Thinking on Science and Technology." *Qiushi*, no. 17 (September 1, 2006). <https://www.opensource.gov/> (OSC document no. CPP20060926701002).

Xue, Lan. "Recent Developments of Chinese Government Policies on High-Tech Industries and Innovation." Public presentation at program, China's Increasingly High Technology Trade: Facts, Policies, and Implications, Brookings Institution and Carnegie Endowment for International Peace, Washington, DC, September 26, 2007. <http://www.carnegieendowment.org/events/index.cfm?fa=eventDetail&id=1064&&prog=zgp&proj=zdl,zgpf>.

Zhang, Z., and S. Yu. "Future HTGR Developments in China after the Criticality of the HTR-10." *Nuclear Engineering and Design*, no. 1 (October 2002): 249–57.

The author also consulted articles in the *Chronicle of Higher Education*, *Financial Times* (London), *International Herald Tribune* (Paris), *New York Times*, ChinaView, U.S. Federal News Service, and *Washington Post*, as well as numerous national and international Web sites, reports, and translations available through the Open Source Center (OSC), and the China National Knowledge Infrastructure (CNKI) Database.