China's Program for Science and Technology Modernization:

Implications for American Competitiveness

Prepared for

THE U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

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About CENTRA Technology, Inc.

CENTRA Technology, Inc. is a private corporation providing security, analytic, technical, engineering, and management support to the government and private sectors since 1985.

CENTRA's China research group employs experienced Chinese language-qualified analysts to provide finished open-source analysis on a variety of topics, including: China's politics, economy, international trade and financial relations, energy sector, environment, military, defense industry, and society. CENTRA maintains a network of expert consultants to provide clients additional insights into these and other issues.

Scope Note

The US-China Economic and Security Review Commission (USCC) contracted CENTRA Technology, Inc. (CENTRA) to provide a report on the scientific modernization program of the People's Republic of China (PRC) and its implications the competitiveness of the United States.

The Commission asked CENTRA to 1) examine and assess national-level programs from the 1980s to the present; 2) assess linkages between China's science policy and its industrial policy; 3) assess the methods commonly employed by the PRC to support its scientific modernization through interactions with the United States and other Western entities; and 4) analyze identifiable policy linkages between the Chinese government's broader science and technology efforts and the capacities of China's defense-industrial complex.

The report addresses the implications for US competitiveness by speculating on the potential for PRC science policies and programs to promote the development of an internationally-competitive national innovation system.

Case studies on the semiconductor, nuclear energy, and nanotechnology sectors in China address these questions in areas relevant to the Commission's interests, while avoiding overlaps with previous and ongoing USCC research.

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Selected Acronyms

CAE: Chinese Academy of Engineering
CAS: Chinese Academy of Sciences
CGNPG: China Guangdong Nuclear Power Group
CMC: Central Military Commission
CMI: civil-military integration
CMIPD: Civil-Military Integration Promotion Department
CNNC: China National Nuclear Corporation
COSTIND: Commission on Science and Technology for National Defense
FIE: Foreign-Invested Enterprise
FTE: full-time equivalent
GAD: General Armaments Department
GRI: government research institute
ICT: information and communications technology
ITAR: US International Traffic in Arms Regulations
KIP: Knowledge Innovation Program
MLP: National Medium to Long-term Plan for the Development of Science and Technology (2005-2020)
MNC: multinational corporation
MOC: Ministry of Commence
MOE: Ministry of Education
MOF: Ministry of Finance
MOP: Ministry of Personnel
MOST: Ministry of Science and Technology
NDRC: National Development and Reform Commission
NIS: national innovation system
NSFC: National Natural Science Foundation of China
OECD: Organisation for Economic Cooperation and Development
PRC: People's Republic of China
R&D: research and development
RMB: Renminbi, the currency of the PRC
S&T: science and technology
SASTIND: State Administration for Science, Technology, and Industry for National Defense
SOE: State-Owned Enterprise
SSTC: State Science and Technology Commission

Executive Summary

Viewing science and technology as the key to economic development and international competitiveness, the government of the People's Republic of China (PRC) has launched ***a comprehensive effort to become an innovative nation by 2020 and a global scientific power by 2050.*** China's effort will draw significantly on the resources and planning role of the state, whose national science programs have long made targeted investments in research and development (R&D) efforts in areas deemed critical to China's economic and military needs.

The Chinese government recognizes that ***national science programs alone are not capable of sustaining the leapfrogging scientific capabilities the PRC now seeks***. Although they have aided China's technological advance substantially, these programs have not yet fostered the widespread commercialization of internationally-competitive technologies originating from Chinese R&D efforts.

China's science and technology (S&T) policy now embraces the idea, conveyed in China's national plans and official speeches, of "speeding up the construction of an innovation system that takes enterprises as the center, the market as guide, with commercialization and research interwoven." The government does not aim to move out of the way of markets. Rather, ***the PRC government has become a leader in a technology commercialization drive.***

- China's S&T bureaucracy has expanded financial support for R&D in corporate enterprises, promoted links between research institutes and commercial firms, and established technology development zones and commercialization bases.

- The National Megaprojects introduced in the *2006 Medium to Long-term Plan for the Development of Science and Technology (2005-2020) (MLP)* involve substantial government investments and incentives for key technology and engineering projects with commercial applications.

China's industrial bureaucracies have also supported high technology industries through subsidies for industry, procurement policies; financial support for enterprises' international expansion, and large-scale investments. In these efforts, the PRC has a mixed record. The government helped China's leading telecommunications equipment manufacturers grow, but has so far failed to foster notable innovation in the semiconductor industry.

- ***The October 2010 Decision of the State Council to Accelerate the Development of 'Strategic Emerging Industries' may herald a new phase in China's industrial policy—one that intensifies the government's focus on promoting high-technology enterprises more than ever before.*** The policy calls for the government to fund and promote investments in new industries in seven key areas of technology.

- Industrial policy measures could potentially stifle innovation, since they involve "picking winners" and diverting investment to firms and projects that may not have the technological wherewithal to compete effectively.

China's national innovation system struggles to balance its need to utilize foreign sources of technology with a desire to nurture homegrown innovation. Nevertheless ***the PRC has positioned itself to reap the benefits of global commercial and scientific networks.***

- Technology transfers from foreign firms continue to be important for Chinese enterprises, most recently in the rail transport, alternative energy, and civilian nuclear sectors. The Chinese government and its commercial enterprises are making greater efforts than in the past to assimilate and improve this technology.

- The growing amount of R&D conducted in China by foreign multinational corporations provides a potentially more promising avenue for the PRC to obtain technological know-how.

- The United States has made substantial contributions to Chinese science, particularly through training Chinese scientists and engineers in its universities, research institutes, and corporations. This corps of talent plays an outsized role in China's technological development. A shared American and Chinese interest in challenges related to climate change, energy, and health has also propelled government-facilitated cooperative science projects and growing academic collaborations.

Yet Chinese fears about dependency on foreign technology have provided the impetus for China's pursuit of "indigenous innovation," an attempt to secure sovereign control over core technological capabilities. "Indigenous innovation" does not call for technological autarky, but for China's foreign interactions to have a laser focus on extracting technology for China's benefit.

- Multinational Corporations (MNCs) have quickly learned that China shapes incentives to acquire technology that will then be then be harnessed for the benefit of its national firms. China has also attempted to fill important capability gaps through espionage and theft of foreign technologies that are often crucial pieces in the United States' high-tech industrial and military dominance.

- These "techno-nationalist" policies (those that enhance China's exclusive interests) also include certain restrictive procurement, standards, and patent policies. Such policies are often at odds with best practices for innovation.

Chinese military capabilities are enhanced by spillovers from China's advancing civilian technology base.

- Reforms in the management of defense industries and the research system—as well as initiatives to link civilian and military research—have facilitated absorption of dual-use technology by the People's Liberation Army (PLA).

- Despite arms embargoes and export restrictions, technology collaborations between Western and Chinese firms have significant spillover benefits for Chinese military technology.

Caught between a tradition of state planning and the need for markets—and between an interest in foreign technology assimilation and the lure of domestically-developed technology—China's innovation system faces an ambiguous future. Coherent-sounding national visions obscure the fact that China's bureaucracies have different interests and pursue different goals. This is the case in China's civilian nuclear program—where a two-pronged approach of buying high-quality foreign technology while investing in indigenous development of next-generation nuclear power was driven more by bureaucratic contention than by a coherent national vision.

China has demonstrated a formidable capacity for technological modernization, but its current system of innovation ultimately imposes limits on China's potential.

- China's national science programs, elite commitments, sustained R&D investments, large cohort of scientists, "China price" manufacturing, huge domestic market, and access to technology and know-how from the international system have proven remarkably effective in enabling China's technological "catch up" and leadership in select areas of technology and manufacturing.

- Yet the Chinese model of science in its present form is unlikely to deliver the types of creative research on which future high-technology leadership will depend. Bureaucratically-driven institutions and programs for science are wasteful. China has yet to show that it can meaningfully use the tools of the state to drive the commercialization of discoveries in research labs in a competitive manner. And the nation's drift in a techno-nationalist direction could compromise China's enabling international scientific links.

Introduction: the Trajectory of China's Scientific and Technological Development[1]

China is no longer just the world's workshop. Manned space ventures, electric cars, and the world's fastest supercomputer all make clear: the People's Republic of China (PRC) is ascendant in science and technology. According to Secretary of Energy Steven Chu, speaking in late 2010, China's recent technological successes constitute a new "Sputnik moment" for the United States.[2]

With China poised to be a leader in clean energy and transportation technologies, Secretary Chu was suggesting a technological challenge on a level that ought to shock the American psyche.[3] China's low-emission coal energy plants, third and fourth generation nuclear reactors, high-voltage transmission lines, alternative-energy vehicles, solar and wind energy devices, and high-speed trains, are all either more advanced than those in the United States, or provide serious competition to American technologies.[4]

The transformation in Chinese technological capabilities is not only apparent in the clean energy and transportation fields. China's high-tech industries have made steady progress in telecommunications and information technology (IT). Significant budgetary commitments for research in nanotechnology, new materials, and other cutting-edge scientific fields have allowed China to play a leading role in the next generation of important discoveries. And advanced military weapons systems (including recently-deployed anti-ship ballistic missiles and a new fighter jet prototype with stealth characteristics), have benefited from advances in the PRC's defense industries and in China's civilian technology base.

The Chinese government has been a major impetus in the PRC's rapid scientific rise. China's leading officials are deeply committed to technological modernization and have provided sustained attention and funding to realize their goals. They view technological development as the key to meeting the economic demands of its 1.3 billion citizens as the world faces a crisis of sustainability.[5] In addition, they see science and technology modernization as a critical factor in reaching a leading position on the world

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[1] The authors acknowledge the contribution and counsel of noted expert on China S&T issues, Dr. Richard P. Suttmeier, relating to portions of this report.
[2] US Department of Energy, "Secretary Chu: China's Clean Energy Successes Represent a New 'Sputnik Moment' for America," November 29, 2010. http://www.energy.gov/news/9829.htm.
[3] See also, Evan Osnos, "Green Giant," *The New Yorker*, December 21, 2009.
[4] US Department of Energy, "Secretary Chu: China's Clean Energy Successes Represent a New 'Sputnik Moment' for America," November 29, 2010. http://www.energy.gov/news/9829.htm; Adam Aston at Greener World Media, "7 Technologies Where China Has the U.S. Beat," *Reuters*, December 7, 2010. http://www.reuters.com/article/idUS376800032720101207
[5] Chinese Academy of Sciences, *The Science &Technology Revolution and China's Modernization: Thinking on China's Science & Technology Development Strategy toward 2050.* The English version is available through a joint publication agreement between Science Press Beijing and Springer-Verlag: *Science and Technology in China: A Roadmap to 2050: Strategic General Report of the Chinese Academy of Sciences* (November 2009).

stage and bringing about "the great rejuvenation of the Chinese nation."[6] With the developed world mired in financial difficulties, China's leaders believe the time is especially favorable for closing remaining technological gaps.[7]

For China to secure its ambitions, however, it will have to overcome significant obstacles. Having started from a low base, China's scientific capabilities are still far from world-class in most areas, while its capacity for technological innovation is far less robust than those of advanced industrial economies, as indices attest.[8] To catch up, let alone overtake the West, China must address some serious problems in its innovation system. Government funding programs for science face many difficulties and China's high-tech industrial policies are often wasteful and harmful to innovation. Chinese scientists and scientific managers admit serious problems of research creativity, fraud and dishonesty, weak accountability for research expenditures, troubled institutional arrangements for managing the nation's scientific efforts, and a serious undersupply of highly qualified scientists and engineers. In addition, inadequate protections for intellectual property rights, underdeveloped methods for allocating capital, weak incentives for innovation in some key industrial sectors, and an educational system more geared to test-taking than cultivating creative thinking affect the performance of the innovation system.

Still, these problems have not stopped China's technological advance or prevented it from laying the groundwork for continued improvement in its innovation capacity. China's corps of research scientists and engineers is expanding, its research facilities have experienced a building boom, its share of publications in global science and engineering journals is quickly increasing, and its patenting activity is growing notably.[9] China's research and development (R&D) spending reached $141 billion in 2010—according to purchasing power parity (PPP) estimates—more than twelve percent of the global total. China is on pace to surpass Japan in 2011 and become the largest source of R&D spending in the world after the United States.[10]

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[6] State Council, *Guojia Zhongchangqi Kexue he Jishu Fazhan Guihua Gangyao (2005-2020) National Medium to Long-term Plan for the Development of Science and Technology (2005-2020),* February 9, 2006. http://www.gov.cn/jrzg/2006-02/09/content_183787_2.htm

[7] Chinese Academy of Sciences, *The Science &Technology Revolution and China's Modernization: Thinking on China's Science & Technology Development Strategy toward 2050.*

[8] The Economist Intelligence Unit in 2009, for example, predicted that China would become the 46th most innovative country in the world by 2013, rising from 54th place that year, one of the most rapid advances of any nation, but still well behind the US, which ranks 4th. This index uses outputs such as patents granted, rates of high technology manufacturing, services and licensing, and inputs such as R&D spending, education levels, and research infrastructure to arrive at its rankings.

[9] National Science Foundation, "Science and Engineering Indicators 2010," overview. http://www.nsf.gov/statistics/seind10/pdf/overview.pdf

[10] US R&D expenditures, by comparison, comprises a third of global R&D spending, with expenditures of almost $400 billion. Gautam Naik, "China Surpasses Japan as Powers Shift," *The Wall Street Journal*, December 13, 2010. http://online.wsj.com/article/SB10001424052748703734204576019713917682354.html?reflink=barrons_redirect; Batelle, "2011 Global R&D Funding Forecast," http://www.battelle.org/aboutus/rd/2011.pdf ; US R&D expenditures, by comparison, compromise a third of global R&D spending, with spending of almost $400 billion.

The 2006 *National Medium to Long-term Plan for the Development of Science and Technology (2005-2020)*—the MLP, for short—serves as the PRC's guiding document on innovation policy and represents an important milestone in China's scientific modernization. Conceding that China's scientific capabilities remain well behind those of Western nations, it calls for China to pursue an ambitious program of scientific development that will allow it to "enter the ranks of innovative countries by 2020," and to become "a global scientific power by mid-century," capable of challenging even the most advanced nations for technological preeminence.[11]

China's emergence as a major force in science and technology has profound implications for the United States. On the one hand, China's technological rise could provide opportunities to advance common global challenges and spur healthy competition—a race to the top in new scientific frontiers. Far from containing China's ambitions, the United States and other Western nations have supported China's technological development. Foreign corporations, universities and scientists, in pursuing mutually beneficial partnerships with Chinese entities, have embedded themselves in China's innovation system.

On the other hand, China's continued advance in science and technology may significantly alter the distribution of global economic, political and military power to the disadvantage of the United States. Successful technological development allows nations to capture new markets and attract resources—such as capital and talent—that might otherwise flow elsewhere. Gains in China's technical capabilities also support military programs that threaten the interests of the United States and its allies. US national power has been built on leadership in science and engineering and an innovation system that has fostered sustained economic prosperity and military superiority. While China remains a long way off from challenging the US for leadership, the trajectories of the two countries warrant serious attention.

Already, the world has seen China's scientific efforts become a bone of contention and suspicion as its advances are directed into areas of competition with other nations. After all, noted PRC President Hu Jintao in a 2010 speech, "a nation's technological competitiveness determines its place and future in international competition."[12] Techno-nationalist practices have at times undermined the mutually beneficial basis for the exchange of knowledge and goods across borders. Instances in which China has created an unfair playing field for foreign companies in the high-tech sphere, or stolen foreign technologies in order to "free ride" on the advances of others, have stimulated fears that foreign nations are not only failing to obtain an adequate return on their significant investments in Chinese science, but that their efforts will come back to harm them in the future—if they have not already.

[11] State Council, *Guojia Zhongchangqi Kexue he Jishu Fazhan Guihua Gangyao (2005-2020),* February 9, 2006. http://www.gov.cn/jrzg/2006-02/09/content_183787_2.htm
[12] Hu Jintao, "Hu Jintao zai zhongkeyuan gongchengyuan liang yuan yuanshi dahuishang jianghua (quanwen)" (Hu Jintao's speech at the member's conference of CAS and CAE-full text), *Xinhua*, June 7, 2010. http://www.gov.cn/ldhd/2010-06/07/content_1622343.htm

For there may be more "Sputnik moments" of the kind described by Secretary Chu, moments in which China's technological achievements suddenly awaken foreign nations and enterprises to the fact that the old paradigms guiding their interactions with the PRC in science and technology are no longer applicable. But it is more likely that China's technological rise will be one of ambiguous developments and incremental advances that only over time register as a serious challenge to the competitiveness of today's most technologically advanced nations. This ambiguity in the trajectory of China's scientific rise, and the seriousness of its impact on American interests, demands a clear assessment of China's national innovation system (NIS).

The Chinese Model of Scientific Development

To assess the Chinese national innovation system, this report focuses on 1) the role of the Chinese state's evolving policies, programs and institutions for science; 2) the role of China's industries and industrial policy in innovation; and 3) the role that China's interactions with the West have had in shaping its technological development. This report cannot comprehensively address all components of the China's innovation system—including such important factors as human resources, the legal system, quality of education, and supply of social capital—but it aims to show the ways in which the Chinese government's innovation goals and understanding about the changing dynamics of innovation are shaping its policy orientation. The report describes and assesses an emerging Chinese model of science that reflects unique historical circumstances and decades of central planning, but which is bending to accommodate new understandings of the drivers of innovation.

But what is the Chinese model of science? How does it function and what does this mean for the future of China's scientific modernization? A defining characteristic of the Chinese model is its tradition of centrally-planned R&D initiatives and the national mobilization of human and material resources to support their implementation. This planning tradition has taken on iconic status among many in China's political and technical communities.

Research planning began in the early 1950s in cooperation with the Soviet Union and became more fully elaborated with the introduction of the 12-Year Plan for Scientific and Technological Development in 1956. These efforts, which emulated those of the Soviet Union, produced a model of top-down, state directed science and technology programs to spur developments in strategically important areas.[13] While the progress initiated by the 12-Year Plan was attenuated by the political instability of the Cultural Revolution in the late 1960s and 1970s, nuclear weapons and space technology flourished under the "*liangdan yixing*" ("two bombs, one satellite") programs. The successes of the

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[13] The priority fields of the 12 year plan included atomic energy, radio electronics, jet propulsion, automation and remote control, petroleum and scarce mineral exploration, metallurgy, fuel technology, power equipment and heavy machinery, problems relating to the harnessing of the Yellow and Yangtze rivers, chemical fertilizers and the mechanization of agriculture, disease prevention and eradication, and problems of basic theory of natural science. For further discussion, see Richard P. Suttmeier, *Research and Revolution,* Lexington, MA: Lexington Books, 1974, pp. 58-61.

strategic weapons efforts reinforced the faith of many Chinese leaders in the importance of government involvement in science and technology.[14]

Government-led science planning and initiatives have remained a priority of Beijing during the post-Mao Zedong reform era. At the 1978 Conference on Science and Technology, Deng Xiaoping reaffirmed China's major commitment to scientific development, arguing that in his "four modernizations" program, the modernization of science and technology was key to the other three modernizations, those of agriculture, industry, and national defense. By the early 1980s, China had settled on a policy orientation of having science and technology "serve economic development." National funding programs for research took shape in the 1980s as part of science and technology (S&T) plans nested in five-year national economic plans, designed to shuttle money to scientific projects deemed critical to economic and military needs. One legacy of this state-centric approach to science has meant that tasks with direct economic and military benefit are favored in China and that applied research is preferred over curiosity-driven discoveries and basic research.

As economic reforms progressed, the role of the state in the innovation system began to change in order to accommodate an economy that was moving away from central planning.[15] By the end of the 1980s, China's science and technology policy was facing new cardinal choices, the resolution of which remain a matter of active debate today, and which introduce ambiguity to the orientation of China's innovation system.

The first of these cardinal choices—the choice between the plan and the market—derived from a new awareness that the absence of market forces imposed enormous costs on the Mao-era innovation system. An active critique emerged in the 1980s and 1990s of the institutions for science and technology that had developed since the 1950s, a critique which was strongly influenced by the new exposure to the United States and other capitalist countries. These nations seemed to rely on the dynamics of the marketplace to drive innovation, with the result that a great deal of their research and innovation occurred in industrial enterprises. Yet, a new appreciation for the role of markets in innovation did not fully dampen the enthusiasm for planning, and Chinese scientists could also point to the US defense research system, where collaborations between public research bodies and private companies were among the most successful tools in achieving disruptive innovation.

A second cardinal choice is the one between foreign and domestic technology, or the extent to which resources should be devoted to conducting R&D indigenously as opposed to acquiring technological assets from abroad. In the post-1978 era, China has acquired vast amounts of know-how from foreign companies, universities and governments. It has greatly expanded international cooperation in science and used international contacts to bring a new level of cosmopolitanism to the research environment, especially through

[14] For a complete list of China's seven S&T plans since the 12 Year Plan, see Liu Li, "Research Priorities and Priority-Setting in China" (Vinnova*:* November 2009).
[15] Richard P. Suttmeier. "Science and Technology Under Reform" in US Congress, Joint Economic Committee, *China's Economy Looks Toward the Year 2000* (Washington: Government Printing Office, 1986).

overseas training of new cohorts of scientists and engineers. The impressive technology advances that China has made over the past thirty years would be inconceivable without its access to international scientific ties and international technology flows. But as China has successfully embedded itself in a network of international S&T linkages, many Chinese question whether the country has become overly dependent on foreign technology in ways that are detrimental to its economy and national security. Some Chinese believe the PRC should strive to develop its own technologies in order to capture new markets; others note that the technologies China needs are those that other nations are not willing to sell. This is the thinking that motivated the preparation of the MLP and its celebration of *zizhu chuangxin*, or "indigenous innovation," and its stress on technological sovereignty.

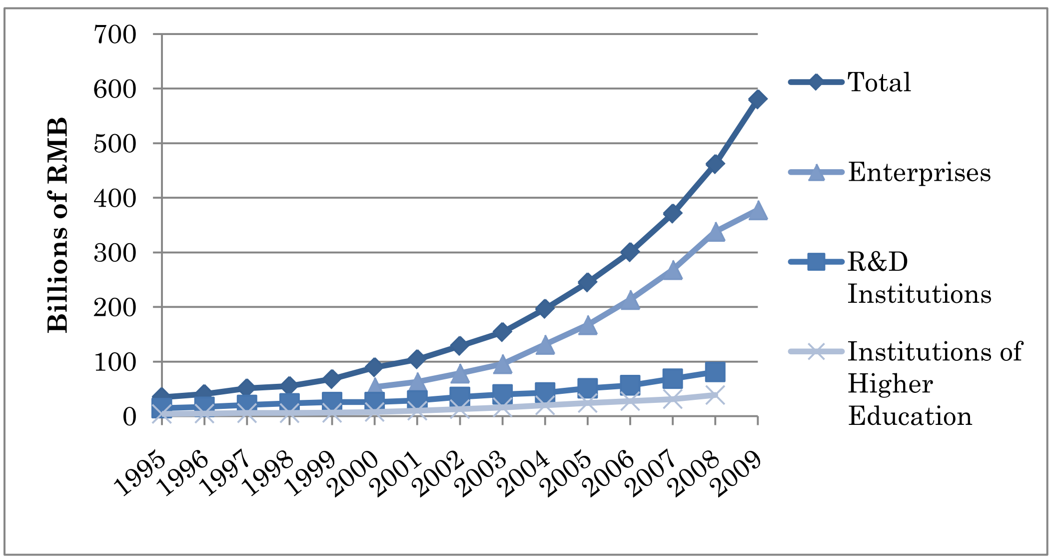
As these choices suggest, debates over the direction of Chinese science are far from abating. Scientists, businessmen, and officials offer different solutions to a range of problems in different technology sectors and scientific fields, with the result that the future of the innovation system is contested. The heavy role of politics and bureaucratic contention in choices about science policy, and an ambivalent attitude of China's planners towards the market and the nation's position in global innovation networks, are capable of producing incoherent policies and changes in direction. China's science policies may yet aid its quest to become an innovative nation; or they may serve to hamper its innovation goals. The path China navigates between planning and free markets—and between international linkages and techno-nationalist retrenchment—will have profound implications for China's innovation capacity and for the United States.

China's National Institutions and National Programs for Science

In the past, China's centrally-directed system of innovation was able to develop new technologies, but failed to serve the innovation needs of industry. As a result of a series of reforms and policy decisions over the past fifteen years, China's national innovation system has undergone significant change. R&D in industrial enterprises—stimulated by government incentives and a desire by firms to enhance their positions in the marketplace—now accounts for approximately 70 percent of all national R&D, according to PRC statistics.[16] Much more attention is being given today to research institute-industry and university-industry relations in the belief that true innovation will only come about from linking forefront research with entities that can commercialize and profit from these findings.

In 2009, China claims to have spent 580 billion RMB (around $85 billion in contemporary exchange rates) on R&D, or 1.7 percent of its gross domestic product (GDP).[17] The rapid rise in R&D conducted by China, and by the enterprise sector in particular, over the past decade, is shown in Figure 1:

Figure 1: Overall Chinese R&D Spending and R&D Conducted by Performer[18]

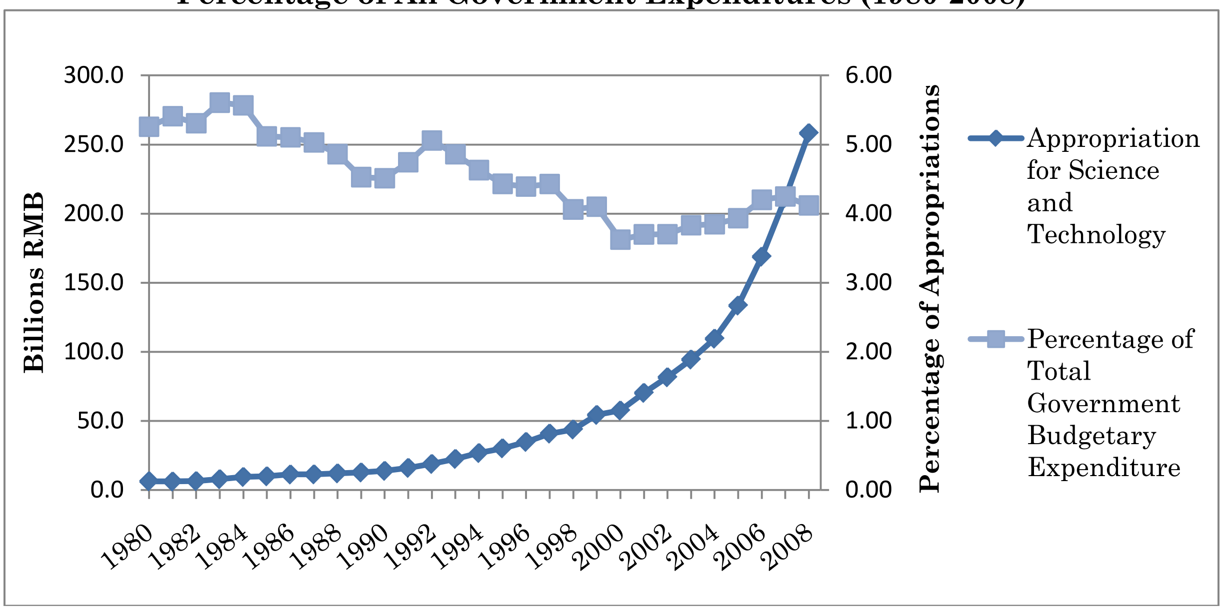


[16] Even though most Chinese companies spend little on R&D by international standards. Explanations for the 70 percent figure could be that a small number of companies (eg. Huawei) spent a great deal on R&D, and that many research institutes which previously belonged to the government have been incorporated into enterprises, or have become enterprises themselves, thus changing the accounting categories. National Bureau of Statistics, Ministry of Science and Technology, *China Statistical Yearbook on Science and Technology: 2009*. Beijing. China Statistics Press.
[17] According to a report by China's National Bureau of Statistics, "Di'er ci quanguo kexue yanjiu yu shiyan fazhan ziyuan qingcha zhuyao shuju gongbao" (the second nationwide science research and development resources inventory: public report on important statistics), November 22, 2010. http://www.stats.gov.cn/tjgb/rdpcgb/qgrdpcgb/t20101122_402684868.htm
[18] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), statistical data CD, Section 1-9;

Despite the growth of research in Chinese enterprises, the role of the government remains central to Chinese science, with national funding programs supporting most of the nation's advanced R&D efforts. State institutions design, fund and implement important research and innovation programs, including many in industry. The Chinese Academy of Sciences and leading universities (all state-run) remain the most important centers for advanced scientific research.

The government's science and technology expenditures (a larger spending category that includes R&D expenditures) have risen dramatically in the last decade, as Figure 2 shows. This growth, in part the result of science's slightly growing share of the government's budget over the past decade, is primarily sustained by fast-rising government revenues. While the government does not contribute as large a share of the national budget to science as it did in the 1980s and 1990s, it still reports appropriating more than 4 percent of its budget for science. This has entailed the Chinese government spending around 0.4 percent of the nation's gross domestic product (GDP) on R&D in recent years (a significant amount, but one that is still lower than the approximately 0.75 percent of GDP spent on R&D by the US federal government over the past decade).[19]

Figure 2: PRC Government S&T Expenditures and S&T Expenditures as a Percentage of All Government Expenditures (1980-2008)[20]



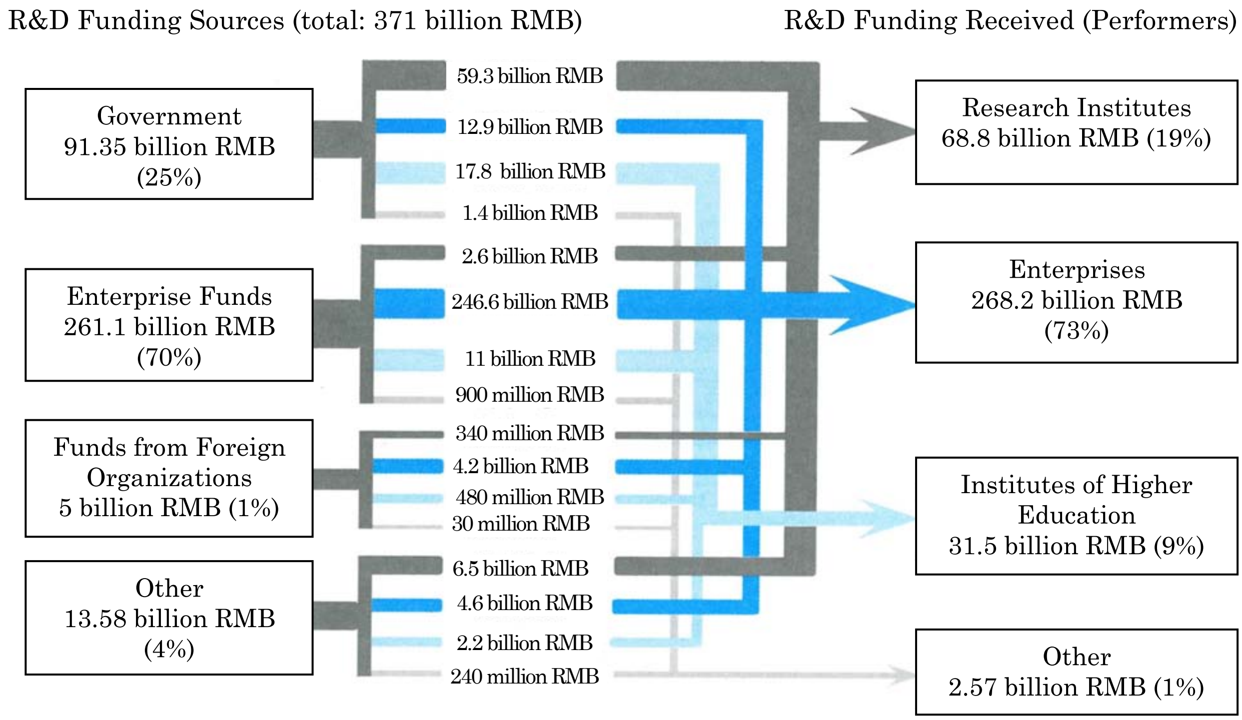
2009 numbers taken from National Bureau of Statistics , "Di'er ci quanguo kexue yanjiu yu shiyan fazhan ziyuan qingcha zhuyao shuju gongbao" (the second nationwide science research and development resources inventory: public report on important statistics), November 22, 2010.

[19] Chinese figures are calculated based on 2007 statistics, when the government spent .37 percent of GDP on R&D. Assuming 25% of R&D spending derived from the Chinese government in 2009, as it did in 2007, China spent .4 percent of GDP on R&D. R&D statistics are from the China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 44; GDP numbers are from Xinhua and the National Bureau of Statistics. US figures are from the NSF: http://www.nsf.gov/statistics/nsf10314/pdf/tab13.pdf

[20] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), statistical data CD, section 1-1.

In the PRC S&T system, R&D funding is provided by the government, enterprises, and other organizations, and goes to research institutes, enterprises, and universities. These money flows can be tracked in the funding matrix below based on data available from 2007.

Figure 3: Money Flows from R&D Funding Sources to R&D Performers, 2007[21]



The government naturally provides financial support to its own research institutes and universities, but it also supports the R&D of enterprises—according to Chinese statistics, to the tune of 12.9 billion RMB a year. That represents 14 percent of the government's expenditures on R&D.[22] Many of the implementing policies associated with the *Medium to Long-Term Plan for the Development of Science and Technology*, including some that have caused considerable international consternation, can best be understood as attempts to strengthen the research and innovation capacity of Chinese companies and make them the preferred recipients of national program funding. Thus, some of the funding from national programs which in the past would have gone to CAS, government research institutes (GRIs) or universities is now going to Chinese companies or is being spent on projects in these government labs that have technology commercialization components linked with Chinese corporate enterprises.

In addition, total national budgetary support for innovation activities in the

[21] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 44.
[22] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 44.

enterprise sector is much larger than R&D spending alone. In 2006, China reported that it allocated nearly 39 billion RMB to enterprises for innovation-related goals. It did so—and potentially on a much larger scale than reported—through tax incentives, subsidies, investments, loans, procurement policies, land grants and patenting support that have become more common in recent years.[23]

China's S&T Institutions

After 60 years of development, China's national innovation system is remarkably extensive, but also of greatly uneven quality. In 2009, there were some 45,000 "R&D organizations of all kinds" (*gelei yanjiu kaifa jigou*) involved in scientific activities and an R&D workforce of approximately 1,426,000 research personnel.[24] To better understand the operation of China's institutions for research and innovation, it is useful to distinguish between the innovation system's research performers and its policy and funding organizations.

Research Performers

China's main research performers today are:

- The Chinese Academy of Sciences (CAS), which operates 100 research institutes;
- 3,707 government research institutes (GRIs) under central ministries and local governments;
- 2,305 institutions of higher education (IHEs), some 1,354 of which report R&D activities; and
- Industrial enterprises, including 29,879 corporate R&D labs.[25]

The Chinese Academy of Sciences (CAS). The Chinese Academy of Sciences has been referred to as the "locomotive" (*huoche tou*), and more recently as the "backbone" (*gugan*), of the Chinese innovation system. With a research staff of some 50,000, it employs much of China's best scientific and engineering talent and has an extensive system of roughly 100 research institutes and laboratories (a full list of CAS institutes is provided in Appendix I). CAS played an important part in China's early scientific advances, particularly in its strategic weapons program, and still plays a critical role in support of China's defense needs as well as its high technology aspirations, notably in information and communications technology (ICT), in energy research, in biotechnology, and in

[23] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 144.
[24] These statistics and others in this section, where not otherwise indicated, are taken from China's National Bureau of Statistics , "Di'er ci quanguo kexue yanjiu yu shiyan fazhan ziyuan qingcha zhuyao shuju gongbao" (the second nationwide science research and development resources inventory: public report on important statistics), November 22, 2010.
[25] National Bureau of Statistics, "Di'er ci quanguo kexue yanjiu yu shiyan fazhan ziyuan qingcha zhuyao shuju gongbao" (the second nationwide science research and development resources inventory: public report on important statistics), November 22, 2010.

nanotechnology. CAS is also a leading force in basic research and in strategic research related to natural resources and the environment, agriculture, medicine, and public health.

Since 1998, and the initiation of the "Knowledge Innovation Program," discussed below, the quantity and quality of CAS research has improved markedly, and it has seen its R&D budget from all sources increased steadily, rising from 9.3 billion RMB in 2004 to 15.4 billion RMB in 2008. Of this, roughly 35 percent was for basic research, 56 percent for applied research, and 9 percent for development. The 2008 figure represented 3.4 percent of national R&D expenditures, down from 5 percent in 1998, indicating not a decline in CAS funding but the expanding role of R&D in the enterprise sector.[26] As a sign of their importance in innovation, researchers in CAS have been responsible for nearly 20 percent of all of China's peer-reviewed scientific papers over the past ten years and almost 25 percent of all of China's citations in scientific journals.[27] CAS also owns over 400 hundred companies spun off from its institutes.[28]

Institutions for Higher Education (IHEs). IHEs are highly important players in the innovation system, the best of them challenging CAS in competition for technical talent and funding, and for national leadership in basic and applied research. Chinese universities have also established a strong commercial identity, having their own spin-off companies and active contract research arrangements with Chinese and foreign companies.

The IHE sector has 275,000 full-time equivalent (FTE-*quanshi dangliang*) personnel engaged in R&D, 81.8 percent of whom are "researchers" (*yanjiu renyuan).* R&D spending in the IHE sector in 2009 amounted to RMB 46.8 billion, a 22.3 percent increase over the 2000 figure, with basic research accounting for a little over 31 percent, 53.4 percent going to applied research, and 15.5 percent to development. More than half (56 percent) of R&D in universities was funded by government (national and local) in 2009, with Chinese companies providing 36.7 percent, and another 1 percent coming from abroad. Spending for *R&D projects*[29] amounted to 34 billion RMB, with a significant share of project funding going to support engineering research (more than 61 percent). General scientific research received 17.4 percent of project funding, agricultural research 6.8 percent, and medical research 8.5 percent. The University sector as a whole produced over 1 million papers and 56,641 patent applications, among which, 36,241 were for invention patents.[30]

Although the above data are drawn from the 1,354 IHEs that report having R&D activities, (out of a total number of 2,305 IHEs), research in the IHE sector tends to be

[26] Chinese Academy of Sciences, Bureau of Planning and Finance. *CAS Statistical Data, 2008.*
[27] Fred Y. Ye, "The Two Engines that Drive Science in China," *Current Science*, Vol. 98, No. 3 (10 February 2010).
[28] See the CAS English website: http://english.cas.cn/
[29] China's science and technology statistical system differentiates between R&D spending, as a more inclusive category, and the narrower category of R&D *project* spending.
[30] Of China's three categories of patents, invention patents are subject careful patent review, and are considered a truer measure of innovation, than utility model and design patents.

dominated by fewer than 50 leading universities, especially by an elite subset of nine institutions referred to as the "Chinese Ivy League," or C9—Beijing University, Tsinghua University, Zhejiang University, Fudan University, Shanghai Jiaotong University, Nanjing University, the University of Science and Technology of China in Hefei, Harbin Institute of Technology, and Xi'an Jiaotong University. These nine universities alone have been responsible for around 25 percent of China's scientific papers and citations.[31]

Government Research Institutes (GRIs). Throughout most of PRC history, GRIs played a leading role in applied research and development. Funded by the government and subordinate to the industrial ministries to which they belonged, they aimed to serve the innovation needs of the entire industry over which the ministry had authority. In 1998, China initiated a major government reorganization and eliminated several industrial ministries, including the ministries of electrical power, coal, machine building, and the chemical industry. In an important reform, 242 research institutes that had been under these ministries either became part of the new state corporations that replaced the ministries, became enterprises themselves, or were transformed into consulting or technical services organizations. Today, most remaining GRIs work less in support of industry and more to support government missions to supply public goods in such areas as agriculture, health, environment, and defense.

In 2009 there were some 3,707 GRIs under central ministries and local governments supporting the missions of their parent government agencies.[32] These institutes employ approximately 277,000 FTE personnel in R&D, 62 percent of whom are "researchers." Not surprisingly, in terms of time commitments, applied research and development consumed most of the effort in this sector. R&D expenditures in the GRI sector amounted to just over RMB 99 billion in 2009, 53.7 percent of which was for experimental development,[33] 35.2 percent for applied research, with only 11.1 percent given to basic research. The great bulk of GRI funding (85 percent) came from government sources, with only 3 percent coming from industry. Funding from foreign sources constituted 0.4 percent. The GRI sector produced 138,000 papers and 15,773 patent applications, 12,361 of which were for invention patents, far fewer in number than in the IHEs and CAS.

Industrial Enterprises. In the past, China's industrial enterprises were not active in R&D, relying instead on the work of the government research institutes under industrial ministries. These institutes were often technically capable, but failed to serve the innovation needs of enterprises, a problem which became more acute with market-oriented reforms. Industrial enterprises are now taking the challenges of innovation far

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[31] Of China's three categories of patents, invention patents are subject careful patent review, and are considered a truer measure of innovation, than utility model and design patents.
[32] These data seemingly include the 100 institutes of CAS as reported by the National Bureau of Statistics.
[33] A term defined for OECD statistical purposes as: "…systematic work, drawing on existing knowledge gained from research and/or practical experience, that is directed to producing new materials, products or devices; to installing new processes, systems and services; or to improving substantially those already produced or installed." OECD Glossary of Statistical Terms. http://stats.oecd.org/glossary/detail.asp?ID=908

more seriously, both in response to market competition and as a result of government policy that seeks to make them the center of the nation's innovation system. Today more than 70 percent of R&D is performed by (and funded by) enterprises. These numbers are, of course, bolstered by the fact that many former research institutes belonging to the government have been incorporated into enterprises or become enterprises themselves.

China now has slightly more than 36,000 industrial enterprises reporting that they are engaged in R&D activities. This includes 1,737 state-owned enterprises (SOEs) (*guoyou qiye*) and companies (*guoyou duzi gongsi*),[34] some 26,418 other Chinese companies, 3,525 firms from Hong Kong, Macao and Taiwan, and some 4,707 foreign invested enterprises (FIEs). The enterprise sector as a whole employs 1,446,000 FTE R&D personnel, more than three times the number employed in 2000. The sector spent 377 billion RMB on R&D in 2009, more than seven times the amount spent in 2000. Of this, 321 billion RMB was spent by large and medium-size enterprises. Broken down by type of enterprises, state-owned enterprises and companies spent about 17 percent of the total, while other Chinese enterprises accounted for 56.5 percent. Enterprises from Hong Kong, Macao and Taiwan accounted for 9.7 percent of the spending in the sector while foreign invested enterprises total 16.7 percent, just slightly less than the SOEs.[35]

Despite the expanded role of the enterprise sector in R&D, the quality of industry R&D remains underdeveloped, and bolstering enterprise research capabilities remains a major policy priority for the PRC. In spite of changes, and the fact that some companies have become leaders in innovation, there is still much dissatisfaction with the research and innovation performance of most enterprises. This is especially true of many SOEs whose profitability is assured by the policy preferences they enjoy, and who therefore are not motivated to undertake risky programs of innovation. Meanwhile, some of China's most innovative firms are smaller startups characterized by vigorous high-technology entrepreneurship (sometimes through partnering with research institutes), but relatively little in-house R&D.

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[34] This refers to 123 State Council-designated "centrally-administered large state-owned enterprises" (*zhongyang qiye*) and other SOEs controlled at the regional level, often referred to as "wholly state-owned companies" (*guoyou duzi gongsi*). The list of 123 large SOEs administered by the State Council's State-owned Assets Supervision and Control Administration (SASAC) can be found at http://www.sasac.gov.cn/n1180/n1226/n2425/index.html.

[35] As National Bureau of Statistics numbers also show, project funding in the enterprise sector in 2009 was almost 319 billion RMB, with 80 percent of these funds coming from enterprise themselves, another 7.8 percent coming from local government science programs, and 6 percent from national-level programs. A small percentage, 2.5 percent, came from other companies. The enterprises themselves performed about 70 percent of the R&D, with universities and government research institutes performing 10.3 percent and 5.6 percent respectively. Chinese companies, other than those funding the research, performed 4.5 percent of the total while foreign entities perform 3.8 percent. Interestingly, research entities in the enterprise sector employed only 180,200 personnel with advanced degrees, 11 percent of the whole, and only 7 percent more than 2000.

Enterprises reported that 50 percent of project spending was for new products, with 30 percent going to improve the quality and functionality of existing products. Energy efficiency attracted 6 percent of the funding, with 3.3 percent going to improve labor productivity, 2.7 percent for pollution reduction, and 1.7 percent for materials. The value of sales of new products in 2009 was 6.6 trillion RMB, accounting for 12 percent of the main business income. Enterprises applied for 226,000 patents in 2009, 34 .8 percent of which were for inventions patents, a 4.4 percent increase over 2000.

A look at R&D spending as a percentage of income (*R&D jingfei/zhuying yewu shouru)* shows R&D among business enterprises to be still largely underdeveloped. For the enterprise sector as a whole, the level of effort to support R&D was only 0.7 percent of income; for large and medium-size enterprises, it was only 0.96 percent. Chinese high technology industries do spend more, but are still not at the level of the world's leading high tech firms.[36]

Policy and Funding Organizations

China's technology policy-making and funding system for science and technology is pluralistic, complex and not easily understood. In terms of government R&D funding, a large share comes via program categories defined from above, with funding decisions largely in the hands of program officers in the funding agencies.

China's Ministry of Science and Technology (MOST) plays a leading role in developing national science policy and in designing and implementing many of the national funding programs. Its programs are nevertheless believed to constitute only about 15 to 20 percent of the national government's expenditures on R&D.[37] The rest comes from the budgets of CAS and the National Natural Science Foundation of China (NSFC), from the National Development and Reform Commission (NDRC) (the economic planning body of the State Council), and from other central ministries (the Ministries of Industry and Information Technology, Education, Public Health and Agriculture, among others).

Local governments (provincial and municipal) have become far more important in supporting R&D and are now spending 40 to 50 percent of all reported government spending on science and are working with national research organizations to establish new facilities for research and innovation within their jurisdictions.[38] Levels of R&D funding for military purposes are not provided in official statistics, but may constitute 15 to 28 percent of national R&D expenditures, according to some outside estimates.[39]

Chinese government expenditures for science and technology are included in annual budgets which are guided by priorities set in five-year economic plans. China's 11th Five-Year Plan ended in 2010, with the 12th Five-Year Plan set to go into effect at the March 2011 plenary session of the National People's Congress. Under the MLP,

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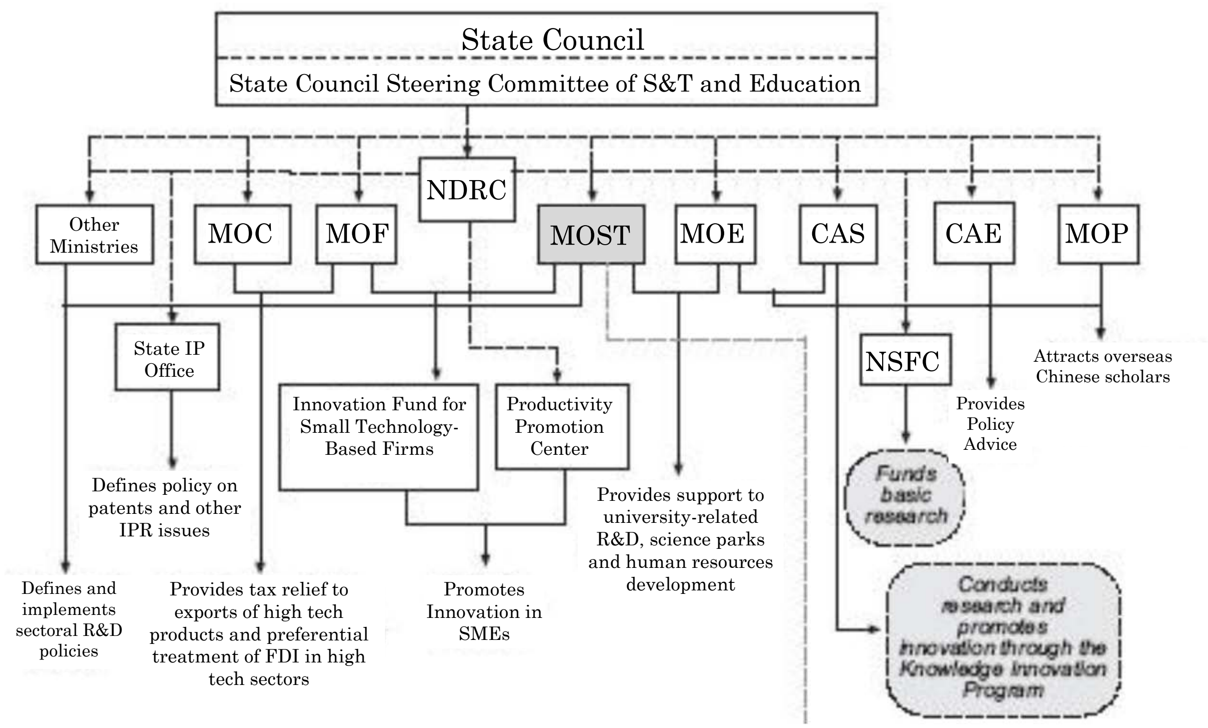
[36] National Bureau of Statistics, "Di'er ci quanguo kexue yanjiu yu shiyan fazhan ziyuan qingcha zhuyao shuju gongbao."
[37] Based on National Bureau of Statistics data provided separately on R&D expenditures and national program expenditures.
[38] In 2008, the OECD reported that local governments were spending about 40 percent of the national governments expenditures. Reportedly, this has increased in the last two years. Organisation for Economic Cooperation and Development, "OECD Reviews of Innovation Policy: China" (Paris: OECD, 2008), p. 78.
[39] See *The Rise of the Chinese Defense Economy: Innovation Potential, Industrial Performance, and Regional Comparisons*, Tai Ming Cheung, ed., Study of Innovation and Technology in China (SITC), an IGCC Project, p. 11.

China's scientific planning horizon was extended to 15 years, but projects are still operationalized within the five-year plans and annual plans and budgets. National programs are multiyear activities which are funded on an annual basis.

China attempts to achieve national S&T policy coordination through a high-level State Council Science and Education Leading Group comprised of the leaders of the major science agencies, including the Director of the NDRC, the Ministers of Science and Technology, Education, Finance, and Agriculture, the Presidents of the Academies of Science and Engineering, the Director of SASTIND (State Administration for Science, Technology, and Industry for National Defense), and the President of the National Natural Science Foundation of China (NSFC). The Leading Group is currently chaired by State Counselor Liu Yandong, a member of the Politburo of the Chinese Communist Party. An organization chart of the government institutions that govern PRC science and technology is shown in Figure 4 below.

Figure 4. Government Structure of Chinese Science and Technology[40]



Chinese experts have called into question the effectiveness of this leadership mechanism and the overall coherence of the government's S&T policymaking process. Bureaucratic entities are seen as executing technology development plans with little coordination across the government. Various entities—and even national program offices

[40] Adapted from Organisation for Economic Cooperation and Development, "OECD Reviews of Innovation Policy: China," Paris: OECD, 2008, p. 428. Note: Key to new acronyms: MOC-Ministry of Commerce; MOF-Ministry of Finance, MOE-Ministry of Education; MOP-Ministry of Personnel

within MOST—have overlapping goals and pursue their missions in a stovepiped fashion that leads to waste and duplication of efforts.[41]

MOST (and its predecessor agency, the State Science and Technology Commission) has long sought to control government science and technology budgets and thus achieve a measure of integration of policy and budgeting, but its ability to do so—other than through the special national program funds it controls—is contested. A good part of the budgets of CAS and NSFC, for instance, come directly from the Ministry of Finance. MOST does have more influence over the science budget of the technical ministries (e.g. the Ministry of Agriculture), but it is not entirely clear how much budgetary control is actually maintained.

As China's R&D expenditures have increased in recent years, questions have been raised about the ability of the science agencies to monitor expenditures. As a result, the Ministry of Finance has assumed a more important role not only in dispensing funds, but also in approving new spending initiatives and monitoring expenditures. It has been doing so, however, with little specialized capability in science and technology policy. Its mechanisms for integrating policy and budgeting, of the sort provided by the Office of Science and Technology Policy and Office of Management and Budget in the United States, are weak.

Major National Programs

The PRC's major national R&D programs represent China's main instruments of science policy, and have enabled some of China's most ambitious and cutting-edge technological developments. China introduced the Key Technologies Program in 1982 and the National High Technology Program ("863") in 1986 to target key deficiencies in sectors crucial to China's long-term competitiveness and national security.[42] In subsequent years, a variety of other national programs were introduced in support of state-led science and technology development. These include the Spark Program for rural technological development, the Torch Program to facilitate the commercialization of new technologies through the establishment of special high technology zones and incubators, the Key Laboratories Program, Engineering Research Centers, and the "973" Program for the support of basic research. The National Natural Science Foundation, modeled on the United States' National Science Foundation (NSF), was established in 1986 to provide small grants to researchers on a peer-reviewed basis. Over the past decade, these programs have evolved as China's innovation system began to focus more explicitly on the development of indigenous innovation capabilities. R&D programs devoted exclusively to

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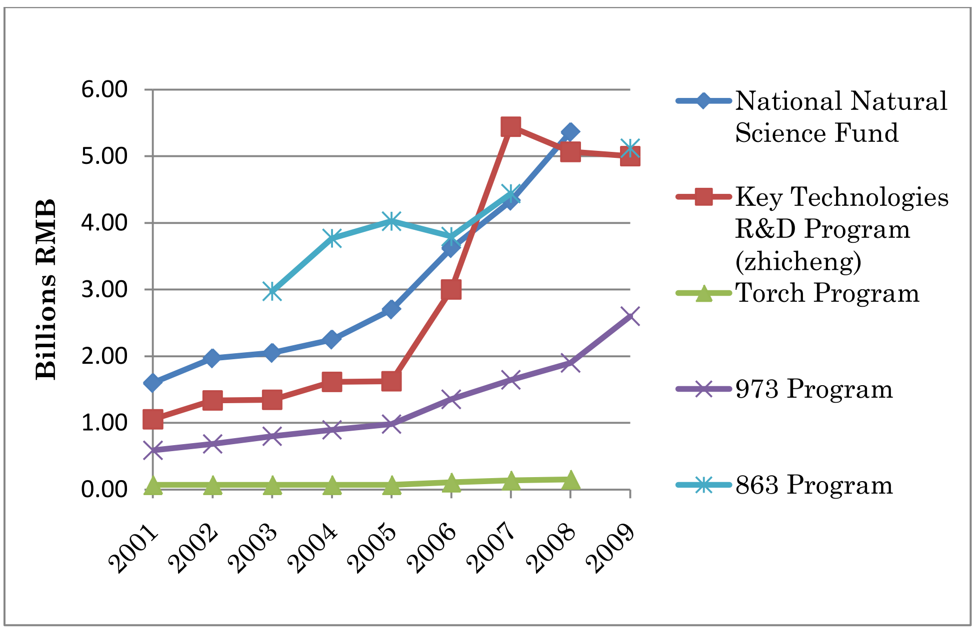
[41] See, for example, Chinese Academy of Engineering News, "Guanyu wo guo 'shierwu' xinxihua fazhan de jiben silu" (basic thinking on the 12th Five Year Plan's informatization development), *Keji yu Chuban*, Issue 7, 2010, p. 62.

[42] Evan Feigenbaum. *Chinese Techno-Warriors: National Security and Strategic Competition from the Nuclear Age to the Information Age* (Stanford, CA: Stanford University Press, 2003); See also, Richard P. Suttmeier. "China's High Technology: Programs, Problems and Prospects" in U.S. Congress, Joint Economic Committee. *China's Economic Dilemmas in the 1990's: The Problems of Reform, Modernization and Interdependence*, 1991.

military applications also exist, described in the report's section on the defense innovation system.

The PRC's premier scientific programs consume only 15 to 20 percent of the government's annual R&D expenditures. While small in terms of overall Chinese spending on science, they are large in their impact on important technologies that China has developed in areas crucial to its international competitiveness. In recent years, the central government has disbursed more funding for these programs than at any other time in their history, as shown in Figure 5 below.

Figure 5: Central Government Appropriations for Major S&T Programs[43]



At any one time, these programs will be funding research in universities, government research institutes, and enterprises. Funds are dispersed through an ostensibly competitive proposal process to projects that address innovation goals as determined by government plans and the administrators of the national programs. Individual scientists and teams seek funds from a variety of national programs, and it is often the case that important scientific efforts will be funded partially by various programs.

[43] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), statistical data CD, Section 5-1; and for 2009 data, MOST, *Annual Report of the State Programs of Science and Technology Development 2010*.

"Key Technologies" ("Gongguan"/"zhicheng")

The "Key Technologies" program, begun in 1983, and known until recently as *gongguan* ("storm the pass"), was an attempt by the State Science and Technology Commission (SSTC), the predecessor of MOST, to revitalize the nation's R&D system and focus it on the needs of industry and agriculture. The Key Technologies Program continues today, having been renamed in 2006 and included in the MLP. Now referred to as the *zhicheng* ("support") program, it is a relatively well-funded program of applied research and development.

Today, *zhicheng* funding supports work in biotechnology, agricultural processing, key manufacturing technologies, the information technology (IT) industry, environmental protection, the development of Chinese medicine, energy and resource exploration, technical standards development, and social development. The program also supported the Beijing Olympics and China's ambitious Western Development Strategy.[44]

Projects under the Key Technologies Program typically last for about three years. They are open to public bidding, with preference given to projects involving industry-university-research institute collaboration. Proposals must show how results will be commercialized; patenting is encouraged and resources are provided to support patent applications.[45]

Annual spending for the Key Technologies Program increased dramatically during the 11th Five-Year Plan period. In 2006, central government spending on the program increased to 3 billion RMB, rising to more than 5 billion RMB in 2007 and 2008.[46] The government's contributions to the research programs account for only about 18 percent of the total costs, with most of the rest coming from the awardees, 70 percent of which were funds from industry.[47]

In 2009, China awarded 5 billion RMB to 111 *zhicheng* programs, with significant funding being allotted to agriculture, transportation, and materials. 600 million RMB went to the textiles, light manufacturing, and steel industries, 900 million went to intelligent transportation, agriculture, biology, and ecological restoration, and almost 1 billion RMB was spent on high-speed rail research. Money was furnished to commercialize and design advanced wind turbines, to build the world's first 800 kV direct current electrical transmission lines, an advanced flotation machine for more efficient mining, and demonstration projects in automated manufacturing.[48]

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[44] Liu Li, "Research Priorities and Priority-Setting in China" (*Vinnova:* November 2009), p. 35.
[45] Organisation for Economic Cooperation and Development, "OECD Reviews of Innovation Policy: China" (Paris: OECD, 2008), p. 459.
[46] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), p.292.
[47] Organisation for Economic Cooperation and Development, "OECD Reviews of Innovation Policy: China" (Paris: OECD, 2008), p. 82.
[48] MOST, *Annual Report of the State Programs of Science and Technology Development 2010*, pp. 83-98.

National High Technology Program ("863")

863 is China's best-known and most strategically oriented national R&D program. In March, 1986, four senior scientists who had been associated with China's strategic weapons programs sent a letter to Deng Xiaoping arguing that the assumptions behind the *gongguan* program were not appropriate for scaling the international high-technology frontier. By the middle of the 1980s, the US had launched its Strategic Defense Initiative, Europe had initiated its Eureka high-technology program, and Japan was promoting its own national efforts in high technology. The scientists claimed a special national program was needed to monitor and research international high-technology trends. Deng Xiaoping approved the proposal. Subsequently, seven sectors viewed as most crucial to China's long-term national security and economic competitiveness were selected to receive government support. The fields of automation, biotechnology, energy, information technology, lasers, new materials, and space technology thus became the priorities of what became known as the 863 Program, after the date it was conceived.[49]

Today, the 863 Program is one of the main supports for the current drive for "indigenous innovation." It is is focused largely on applied research and is organized around nine principal areas of high technology—the seven areas of technology described above, with the addition, in the mid-1990s, of ocean technology and resources/environment technology.

The 863 program has had as a major focus on pushing the civilian economy to higher levels of value-added production, with MOST and its predecessor, SSTC, administering the majority of 863 program categories. The space and laser programs, however, have been administered by the military research establishment through the Commission on Science and Technology for National Defense COSTIND (now SASTIND). In addition, much of the work conducted on the IT program has been of a dual use nature (for more on the 863 Program and military R&D, see page 116).

As with the Key Technologies Program, funding for 863 over the past decade has not only risen, but has increasingly been channeled to Chinese enterprises, as opposed to research institutes and universities, and more complex patterns of government-industry-university funding and cooperation are also emerging. The central government's share of funding for 863 is in the neighborhood of 45 percent, with the rest coming from industry and local governments.[50]

During the 10th Five Year Plan (2001- 2005), the 863 Program attempted to lay the foundation for the "leapfrogging" aspirations now found in the MLP.[51] Nineteen

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[49] Evan Feigenbaum. *Chinese Techno-Warriors: National Security and Strategic Competition from the Nuclear Age to the Information Age.* Stanford, CA. Stanford University Press. 2003, p. 157; See also, Richard P. Suttmeier. "China's High Technology: Programs, Problems and Prospects." In U.S. Congress, Joint Economic Committee. *China's Economic Dilemmas in the 1990's: The Problems of Reform, Modernization and Interdependence*. 1991.
[50] Organisation for Economic Cooperation and Development, "OECD Reviews of Innovation Policy: China" (Paris: OECD, 2008), p. 22
[51] Leapfrogging in this context means to jump ahead to current levels of technology without having

priority projects in four areas, in particular, received attention: the construction of China's information infrastructure; agricultural and pharmaceutical biotechnology; energy resources and environment protection; and new materials and advanced manufacturing. The latter category included nanotechnology and other new materials of relevance to aviation, maglev trains, and information storage and access.[52]

In 2009, 863 funded 110 new programs, with the government allocating 5.1 billion RMB. These funds were divided among programs in IT (23.5 percent), manufacturing (15.5 percent), materials (14.7 percent), resources and environment (9.4 percent), "earth observation" (8.8 percent), transportation (7.3 percent), "oceans" (5.9 percent), biology (5.2 percent), energy (5 percent), and agriculture (4.7 percent). These figures do not include 863 expenditures for military-specific programs.[53]

863 funds recently supported the development of China's Tianhe-1A supercomputer, which in October 2010 overtook Oak Ridge National Laboratory's Jaguar as the world's fastest computer. The computer was developed at the National University of Defense Technology (NUDT). The 863 Program also supported the successful refining of engineering technologies in the production of "Kevlar" para-aramid (*duiwei fanglun*) fabrics used in body armor, an efficient 3kW solid-state laser and associated welding equipment, and internet monitoring systems.[54]

The Basic Research Program ("973")

By the beginning of the 1990s, the SSTC felt the need to support more basic research and initiated the State Fundamental Research Key Program (the National Climbing Program-*Pandeng*) to that end in 1991. In 1997, *Pandeng* was superseded by the "973" Basic Research Program, with the following objectives: 1) Support multidisciplinary and fundamental research of relevance to national development; 2) Promote frontline basic research; 3) Support the cultivation of scientific talent capable of original research; and 4) Build high-quality interdisciplinary research centers.[55]

As with NSFC programs discussed below, 973 includes a number of more applied projects that might be considered "oriented-basic" research. Projects cover a range of categories (agriculture, energy, IT, environment, health sciences, materials, interdisciplinary research, forefront science, protein research, quantum manipulation research, nanotechnology, development and reproduction) and typically involve proposals submitted by teams of investigators for projects typically lasting for five years (and which are subject to expert review after two years). Funding for 973 has also grown significantly over the past decade and is fairly evenly divided across program categories, with almost

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to pass though the intervening stages.
[52] Liu Li, "Research Priorities and Priority-Setting in China," *Vinnova*, November, 2009, p. 36.
[53] MOST, *Annual Report of the State Programs of Science and Technology Development 2010*, p. 54.
[54] A longer discussion, in Chinese, of recent achievements can be found on pages 54 to 82 of MOST, *Annual Report of the State Programs of Science and Technology Development 2010*.
[55] Liu Li, "Research Priorities and Priority-Setting in China," (*Vinnova*: November 2009), p. 39.

all going to research institutes and universities. Approximately 90 percent of the funding support for 973 comes from government sources.[56]

In 2009, the 973 Program supported 123 new scientific programs and 424 ongoing projects at a cost to the government of 2.6 billion RMB. These programs led to the creation, according to MOST, of the world's first light quantum telephone network, the growth of the first living mice developed through induced pluripotent stem (iPS) cells (an important step for their use in developmental biology and regenerative medicine), and advances in low cost solar batteries. The 973 Program also supported a number of projects in applied research, such as one that improved the accuracy of GPS satellites to within 50 meters and that was installed in the ground pre-processing systems of Chinese-produced satellites.[57]

The fact that the "China Basic Research Program" supports applied research reflects the fact that, in China, support for investigator-driven basic science is largely secondary to applied technologies that can be commercialized or used in national defense.[58] China devotes relatively little funding overall to basic research. Although China's spending on basic research has increased substantially to some 27 billion RMB in 2009, that figure represented only 4.7 percent of its total R&D spending, with the rest going to applied research (12.6 percent) and development (82.7 percent).[59] By contrast, industrialized countries spend considerably more on basic research, ranging from 14 to 22 percent of R&D expenditures.[60] Interestingly, the percentage of China's R&D expenditures on basic research has fallen since the initiation of the MLP, as shown in Figure 6 below.

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[56] Organisation for Economic Cooperation and Development, "OECD Reviews of Innovation Policy: China" (Paris: OECD, 2008), p. 82.

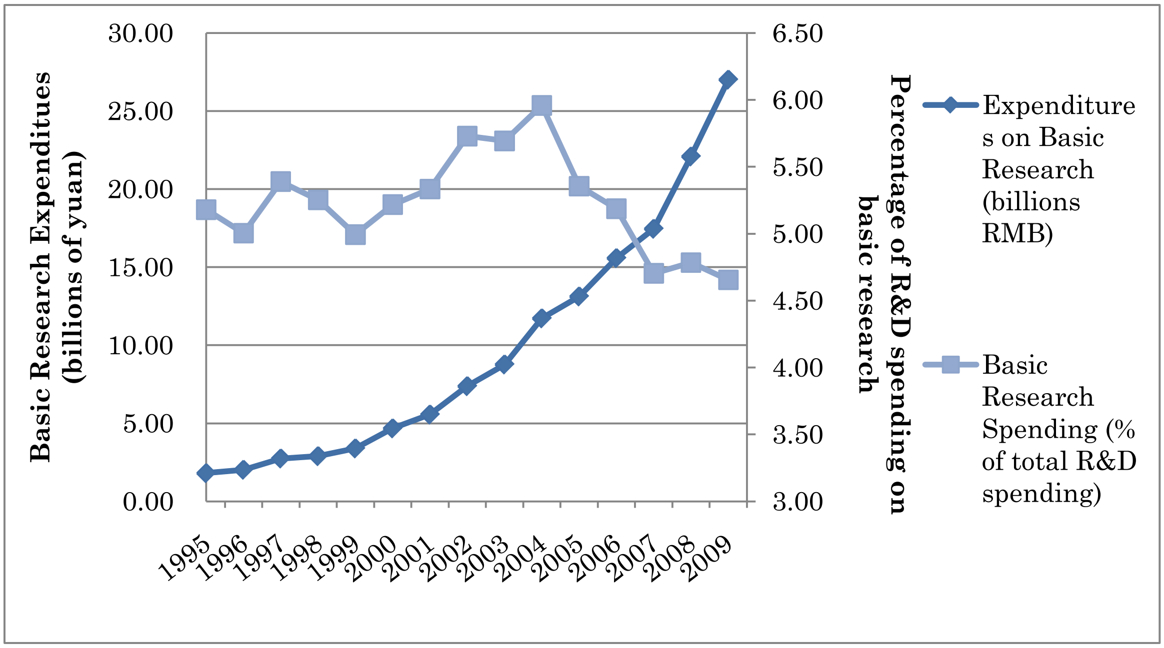
[57] A longer discussion, in Chinese, of recent 973 achievements can be found on pages 23 to 53 in MOST, *Annual Report of the State Programs of Science and Technology Development 2010*.

[58] Zhao Liyu et. al. "*Shixian keji touru mubiao qiangdu de xietiao jizhi yanjiu*" ("Research on adjusting mechanisms to realize the goal of higher R&D intensity"), *Keji Jinbu yu Duice* (*Science & Technology Progress and Policy*), Vol. 7 No. 11, June 2010, p. 9.

[59] National Bureau of Statistics, "Di'er ci quanguo kexue yanjiu yu shiyan fazhan ziyuan qingcha zhuyao shuju gongbao" (the second nationwide science research and development resources inventory: public report on important statistics), November 22, 2010. http://www.stats.gov.cn/tjgb/rdpcgb/qgrdpcgb/t20101122_402684868.htm

[60] Somi Seong, Steven W. Popper, Kungang Zheng. "Strategic Choices in Science and Technology: Korea in the Era of a Rising China," *RAND*, 2005, p. 38.

Figure 6: China's National R&D Expenditures on Basic Research[61]



NSFC Programs

As part of the efforts to reform and reorient China's science and technology system in the 1980s, China became intrigued with the idea of a national science foundation, modeled somewhat after the US NSF, to support investigator-initiated basic research and employ Western ideas of peer review. This led to the establishment of the National Natural Science Foundation of China (NSFC) in 1986. Over time, NSFC has become an important source of funding for pre-commercial research at universities and CAS, and although it continues to be an important source of basic research funding, its mission has expanded to support application-oriented research under its "key" and "major" programs which support both individual investigators and larger team-based projects.

NSFC grants are typically much smaller grants than those provided by China's other major science programs, often in the hundreds of thousands of yuan, rather than the tens and even hundreds of millions of yuan for single projects seen in the grants from 863 and 973.[62]

NSFC also runs a "major research plan" category that includes programs on basic scientific issues for near space flight, quantum mechanics, nano-manufacturing, and emergency management.[63] In addition, NSFC supports programs for the cultivation of

[61] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), statistical data CD, Section 1-8.
[62] see nanotechnology case study.
[63] National Natural Science Foundation of China, "Guide to Programs." http://www.nsfc.gov.cn/english/06gp/index.html

talent (a Distinguished Young Scientists program and a Young Scientist Fund) and research infrastructure development. NSFC's budget has grown by over 20 percent per year since 1986, and has quadrupled since 2001, totaling 7.3 billion RMB in 2010.[64]

The "Knowledge Innovation Program" and "Innovation 2020" of the Chinese Academy of Sciences

The Chinese Academy of Sciences (CAS) was established in 1950 on the foundations of pre-existing Academia Sinica and Beiping Academy, but with a new orientation inspired by the Soviet Academy of Sciences. CAS came to play a major role in scientific development during the 1950s and 1960s, undertaking important work in support of China's strategic weapons programs. By the 1980s, however, the role of CAS was increasingly called into question. CAS's connection to the economy was weak, its pool of human resources aging, and its facilities neglected. For almost two decades, it sought a formula for reinventing itself. A major new effort to this end began in 1998 with the initiation of the "Knowledge Innovation Program," or "KIP." KIP is a well-funded program outside the direct control of MOST that has allowed CAS to transform itself through the rejuvenation of personnel, facilities, and research agendas. The goal of the KIP program has been to have 30 of its institutes recognized internationally as important centers of research by 2010, with five considered world-class.[65]

During the first seven years of the program, from 1998 to 2005, attention was focused on new construction, arranging for the retirement of older unproductive researchers, recruiting a new generation of scientists, and conducting major managerial reform to enhance incentives for scientific outputs.[66] During the last five years, efforts have been made to devise significant interdisciplinary R&D programs to serve national needs and to establish new facilities in cooperation with local governments. The interdisciplinary initiatives have employed what has been known as the "10+1" formula, in which major projects were pursued at one of 10 research "bases," each led by one of the CAS vice presidents, with the "1" being a program of interdisciplinary basic research intended to support the work of the bases. Projects done at the bases involved drawing together human and material resources from various CAS institutes. The 10 bases are for:

- Information Technology;
- Optical Electronics and Space Science Technology;
- Advanced Energy Technologies Material Science;
- Nanotechnology;
- Advanced Manufacturing;
- Population, Health, and Medical Innovation (including brain research in cognitive science, population and public health, and pharmaceuticals);
- Advanced Industrial Biotechnology;

[64] National Natural Science Foundation of China, *AnnualReport.* http://www.nsfc.gov.cn/english/09ar/2009/pdf/004.pdf.
[65] See Richard P. Suttmeier, Cong Cao and Denis Fred Simon, "China's Innovation Challenge and the Remaking of the Chinese Academy of Sciences," *Innovations,* Summer 2006, pp. 78-97.
[66] Organisation for Economic Cooperation and Development, "OECD Reviews of Innovation Policy: China" (Paris: OECD, 2008), p. 458.

- Sustainable Agriculture Ecology and Environmental Protection;
- Natural Resources in Ocean Technologies; and
- Research Involving Large Research Facilities.[67]

More recently, there have been efforts to reach out to local governments to help meet the innovation needs of local economies, and take advantage of increasingly generous funding offered by some of the more wealthy localities. Among these efforts is the establishment of seven new institutes with support from local governments, including the:

- Institute of Biomedicine and Health (Guangzhou)
- Institute of Urban Environment (Xiamen)
- Institute of Coastal Zone Research (Yantai)
- Institute of Nano-tech and Nano-bionics (Suzhou)
- Institute of Bioenergy and Bioprocess Technology (Qingdao)
- Institute of Material Technology and Engineering (Ningbo)
- Institute of Advanced Technology (Shenzhen)

The KIP ended in 2010, and its results are undergoing an extensive internal evaluation. Although not all of its ambitious goals are likely to have been reached, CAS has clearly re-emerged as a crucial center for basic research, high technology, and science in support of public goods. World-class research can be found in a number of its institutes, such as the Institutes of Physics and Chemistry in Beijing and the Dalian Institute of Chemical Physics. The efforts to rejuvenate CAS have begun to pay off as seen in its ability to secure funding from national programs. In 2002, for instance, it was the beneficiary of 20 percent of the NSFC's spending, 14 percent of 863 expenditures, and multiple projects supported by the 973 Program.[68] Important areas of high technology showing notable progress include catalysis, energy, new materials, nanotechnology, and sensors and "the Internet of Things."[69]

CAS is keen to launch a follow-on program to the KIP that would again produce a dedicated funding stream from the Ministry of Finance. To this end, the Academy is in the process of launching a new "Innovation 2020" program that will establish new bases for cutting-edge interdisciplinary research, and further collaboration with local governments. Innovation 2020 also calls for the initiation of a new R&D agenda of "Vanguard" projects in such fields as advanced nuclear power, space science, next generation coal technology, stem cells and regenerative medicine, and climate change monitoring.[70]

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[67] Richard P. Suttmeier, Cong Cao, and Denis Fred Simon, "Knowledge Innovation and the Chinese Academy of Sciences," *Science*, v. 312, n. 5770 (April, 2006), pp. 58-59

[68] Organisation for Economic Cooperation and Development, "OECD Reviews of Innovation Policy: China" (Paris: OECD, 2008), p. 458.

[69] See, for instance, Chinese Academy of Sciences, "China to construct Internet of Things," September 28, 2009. http://english.cas.cn/Ne/CASE/200909/t20090928_44783.shtml.

[70] *People's Net*, "Bai Chunli: 2010 nian zhongkeyuan jiang xianxing qidong 'chuangxin 2020' shidian (Bai Chunli: 2010 CAS will prioritize the intitation of 'innovation 2020' exercise)," January 25, 2010. http://scitech.people.com.cn/GB/10839418.html.

Problems in Government-Sponsored Science

Although China's science and technology planning system is generally celebrated in word and deed, China's system of state research funding has also come under heavy criticism from scientists and some technocrats for problems they allege are slowing down China's pace of innovation. In 2004, MOST Vice-Minister Ma Songde said that many of his agency's 863 projects experienced "administrative interference with academic research," a "lack of fairness" in the selection of projects, gaps between promises and achievements, and numerous instances of fraud and deception.[71]

Scandals in government-funded microchip development in the 2000s unearthed a culture of poor oversight, wasted resources, and pervasive corruption in some national science projects. For instance, ARCA Technology Corp., which received 15 million RMB during the 10th five year plan from the 863 program to develop a next-generation CPU chip, failed to deliver the specified product, but paid it employees unlawfully high sums and speculated in real estate. Even more sensational was the Hanxin ("China chip") scandal. Chen Jin, an American-trained professor at Shanghai Jiaotong University was lavished with millions of RMB in government R&D funding after developing what he described as China's first indigenous digital signal processor (DSP) chips, the Hanxin. By the end of 2005, complaints began to emerge that Chen's "China chip" was a fake. As described in the Chinese press, Chen Jin's only innovation was to buy American-made Motorola chips, scratch off their trademark, and replace them with Hanxin symbols.[72]

Similarly, problems of fraud have been uncovered in much of China's published work in science, calling into question China's impressive record of publications. Scientists are incentivized to publish prolifically, while there is little accountability for the results of research. A recent government study found that a third of 6,000 scientists at six of the nation's top institutions admitted to engaging in plagiarism or the outright fabrication of research data.[73]

Criticism of China's national science efforts go beyond a few outright scandals. Government programs have been accused of ignoring merit and feasibility altogether in their selection of projects. According to Yigong Shi and Yi Rao of Tsinghua University and Peking University, this is how bureaucratized science functions in the PRC. They write in a 2010 volume of *Science*:

> Although scientific merit may still be the key to the success of smaller research grants, such as those from China's National Natural Science Foundation, it is much less relevant for the megaproject grants from various government funding agencies, which range from tens to hundreds of millions of Chinese yuan….For the

[71] Jin Zhenrong, "863 jihua guanli jiang gengjia gongkai gongzheng – fang kejiby fubuzhang ma songde" (863 Plan management will be more open and fair: interview with MOST vice-minister Ma Songde) *Guangming Ribao*, August 8, 2004. http://www.gmw.cn/01gmrb/2004-08/30/content_89716.htm
[72] Wu Zhong, "Two Chip Scandals Set Back China's IT Industry," *Asia Times*, July 4, 2006, http://www.atimes.com/atimes/China_Business/HG04Cb06.html
[73] Andrew Jacobs, "Rampant Fraud Threat to China's Brisk Ascent," *The New York Times,* October 7, 2010. http://www.nytimes.com/2010/10/07/world/asia/07fraud.html

> latter, the key is the application guidelines that are issued each year to specify research areas and projects. Their ostensible purpose is to outline 'national needs.' But the guidelines are often so narrowly described that they leave little doubt that the 'needs' are anything but national; instead, the intended recipients are obvious. Committees appointed by bureaucrats in the funding agencies determine these annual guidelines… 'Expert opinions' simply reflect a mutual understanding between a very small group of bureaucrats and their favorite scientists…To obtain major grants in China, it is an open secret that doing good research is not as important as schmoozing with powerful bureaucrats and their favorite experts.[74]

As a result of this politicized process for receiving funding, the authors say, an "unhealthy culture…permeates the minds" of China's researchers and ensures that scientists have little time to do actual science.[75]

In addition to these problems, government-sponsored programs have faced criticisms for not being cost-effective and producing largely derivative work. Often, the programs have not produced the kinds of creative science and original innovation that investigator-driven research and more market-oriented approaches to innovation might yield.[76]

Cognizant of these deficiencies, China's leaders are determined to make changes to its national programs. They have sought to introduce principles of peer review into the program selection process, although these efforts have been hampered by problems of finding adequate numbers of qualified and disinterested reviewers, and by continued bureaucratic interference.

China's national programs are now also regularly subject to evaluation. The first five years of the MLP are currently being evaluated, a major new evaluation of 25 years of the NSFC is underway, and as noted above, CAS is evaluating the KIP program. A major evaluation report of the 863 Program was completed in 2000 and documented successes in technology catch-up resulting from the program. Some Chinese scientists and planners, meanwhile, hope that larger reforms to the national innovation system can reduce the problems of top-down government-sponsored science. Importantly, some measures introduced in the MLP regarding project funding processes and oversight appear to recognize certain problems regarding incentives and performance in state sponsored-science.

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[74] Yigong Shi and Yi Rao, "China's Research Culture," *Science* Vol. 329, September 2, 2010. www.sciencemag.org.
[75] Yigong Shi and Yi Rao, "China's Research Culture," *Science* Vol. 329, September 2, 2010. www.sciencemag.org.
[76] On the latter point, see Dan Breznitz and Michael Murphrey, "Run of the Red Queen," *China Economic Quarterly*, September 2010, pp. 21-25.)

Other National Programs

Programs for Applications and Commercialization

Since the late 1980s, China has also initiated a series of programs intended to accelerate the application of research results. Most are included in China's budget for "science and technology," a more inclusive budget category than "R&D." The "Spark Program" was initiated in 1986 to stimulate the dissemination of science and technology to rural areas. In 2001, a new Agricultural S&T Transfer Fund was established by the Ministry of Finance to promote and diffuse new agricultural technologies.

The Torch Program began in 1988, with the objective of stimulating industrialization of high technology through the creation of incubators and high technology zones. The Torch Program now supports commercialization activities in IT, biological and medical technologies, new materials, machinery and electronics, new energy sources and energy efficiency, and environmental protection. Both Spark and Torch are MOST programs, but roughly 70 percent of the funding for the activities of the Spark and Torch comes from industrial enterprises themselves.[77]

Other programs introduced during the 1980s and 1990s include the State Key and New Product Program (1988), the Innovation Fund for Small and Medium-Sized Enterprises (1999, targeting innovation in electronics and IT, biotechnology, materials, automation, environment, and energy, with government support of 3.5 billion RMB in 2009),[78] the Special Technology Development Project for Research Institutes (1999), and the Action Plan for Promoting Trade by Science and Technology (2000, in conjunction with the Ministry of Commerce). A new national program designed to promote the indigenous innovation theme of the MLP is the National New Products Program (with its roots going back to a 1988 program of the same name). It aims to support the development of products incorporating Chinese-developed intellectual property, having high export potential, capable of replacing imported products, or made primarily with domestic components.

Assessing the value of these programs is difficult. On one hand, they have probably involved a fair amount of waste and misuse of funds. On the other hand, there is a real need for supporting the commercialization of technologies and for technology extension services. The establishment of science parks and high tech zones through Torch and other programs has undoubtedly produced a real estate bonanza for some, but it is also the case the some of these special zones are successful, having achieved the technological clustering and agglomeration effects of places like Silicon Valley and Boston's Route 128.

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[77] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), pp. 301-2.
[78] MOST, *Annual Report of the State Programs of Science and Technology Development 2010*, p. 3.

Facilities

In 1984, China initiated its first "State Key Laboratory Program," which by 2007 was supporting the work of 189 laboratories in universities, CAS, government research institutes, and enterprises. In the early 1990s, China secured loans from the World Bank for a separate National Key Laboratory Program and for a series of Engineering Research Centers, the latter numbering some 187 in 2005. Key laboratory status is quite competitive and carries with it special funding benefits.

China also supports 20 "National Laboratories" having a status higher than key laboratories. Four of these began in the 1980s and 1990s, with another set begun in 2003, and 10 more in 2006. A list of these important new facilities can be found in Appendix II.

In 2008, the NDRC initiated a new program of "national engineering laboratories" intended to support upstream engineering research on generic technologies. The majority of these are in industry, with some in universities and CAS as well.

In addition, "big science" facilities are being built. These include the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) and the China Spallation Neutron Source.[79] Few Western countries can afford to build world-class facilities of this sort under current financial constraints, and as a result China is becoming a magnet for researchers from around the world seeking to use the facilities.

Talent

China claims a total R&D workforce of approximately 1,426,000 research personnel. Of these, 23 percent have advanced degrees. When all industrial research is included, the R&D workforce in terms of full time equivalents was 2,290,000. The overwhelming majority of R&D personnel is engaged in experimental development, with only about 7 percent in basic research and another 13 percent in applied research.[80] China has also reared an increasing number of scientists and engineers in the last decade. By 2008, China had nearly 3.5 million scientists and engineers, a 68 percent increase since 2000 (see figure 7).[81]

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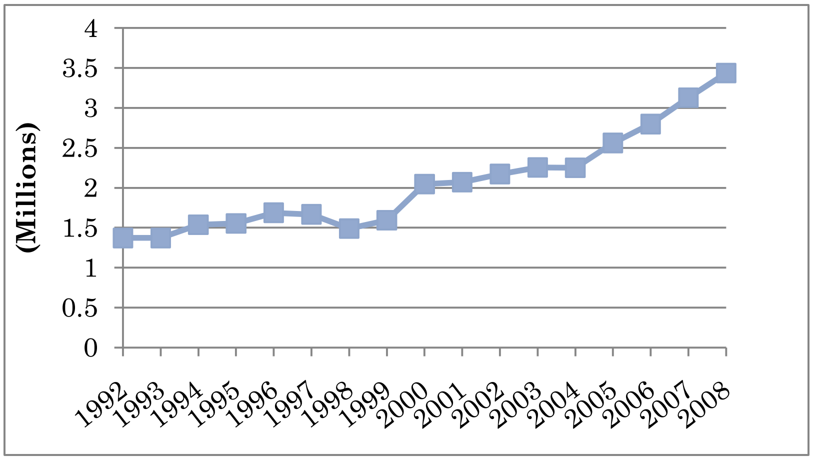
[79] For a full list, see the CAS English website, "Big Science Facilities," http://english.cas.cn/Re/Fac/.
[80] The discussion which follows is based on data for 2009 found in the November 22, 2010 report from the National Bureau of Statistics, and available at http://www.stats.gov.cn/tjgb/rdpcgb/
[81] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), statistical data CD, section 4-1.

Figure 7: China's growing ranks of scientists and engineers[82]



In spite of the overall abundance of scientists and engineers, a serious shortage of world-class researchers is one of the biggest obstacles to China reaching its science and technology aspirations.[83] To train and recruit a new generation of creative scientists and engineers, China has initiated a number of national programs to address the problem. These include those run by the Ministry of Education, by CAS, by NSFC, and by the Ministry of Personnel.

The Ministry of Education operates two programs, "211" (begun in 1993), and "985" (begun in 1998), that are intended to improve the status of China's leading universities and recruit key talents. The 211 program aims to raise some 100 institutions to international levels, with the 985 program focusing on ten universities that should achieve "world-class" status by the early 21st century.[84] The Ministry also administers the Cheung Kong scholars program, started originally with a grant from Hong Kong billionaire Li Ka-shing, which supports the establishment of endowed professorships for outstanding young and middle-aged scholars. In 2004, the Ministry initiated its High-Level Innovative Talent Program as a comprehensive recruitment effort available to leading Chinese universities.[85]

The CAS "100 Talent Program" began in 1994 and has since been incorporated into the KIP. It provides attractive salary, research support, and housing incentives for young scientists, with a particular focus on those working overseas. The NSFC has operated its

[82] National Bureau of Statistics, Ministry of Science and Technology. *China Statistical Yearbook on Science and Technology: 2009* (Beijing: China Statistics Press, 2009), statistical data CD, section 4-1.
[83] Denis Fred Simon and Cong Cao, *China's Emerging Technological Edge: Assessing the Role of High-End Talent* (Cambridge and New York: Cambridge University Press, 2009).
[84] Denis Fred Simon and Cong Cao, *China's Emerging Technological Edge: Assessing the Role of High-End Talent,* p. 44 ff. See also, Jessica Shepard, "China's Top Universities Will Rival Oxbridge, Says Yale President," *the Guardian*, February 2, 2010. http://www.guardian.co.uk/education/2010/feb/02/chinese-universities-will-rival-oxbridge.
[85] Denis Fred Simon and Cong Cao, *China's Emerging Technological Edge: Assessing the Role of High-End Talent,* p. 50.

Distinguished Young Scholar Program since 1994 to support outstanding research projects from promising young scientists, and has regularly increased the value of the awards. In 2005, a special subprogram focused on ethnic Chinese of foreign nationality was established to provide incentives for them to work full-time in Chinese institutions.[86]

Finally, the Ministry of Personnel has since 1995 administered the "100, 1000, and 10,000 Talent Program," which seeks to identify promising scientists, 100 of whom by the year 2010 will be active at the international research frontier, 1000 of whom can be expected to be leaders of advanced research projects, and 10,000 of whom will be capable of high-quality leadership for the development of academic disciplines.[87]

In June 2010, China introduced its Medium and Long-Term Talent Development Plan (2010-2020), which aims to raise the overall level of human resource capabilities and increase the number of college-educated members of the work force to 20 percent from its current 9 percent, with particular emphasis on technical and professional training.[88] As a sign of the serious political commitment to human resource development, Li Yuanchao—a promising young leader who heads the Organization Department of the Chinese Communist Party—led the preparation of the Plan.

The National Medium to Long-term Plan for the Development of Science and Technology (2005-2020)

The most recent, and arguably the most ambitious, of China's national science plans, is the current *15 year National Medium to Long-term Plan for the Development of Science and Technology (2005-2020).* Introduced in January 2006, the product of two years of meetings and consultations with well over 2000 members of the technical community, the MLP offers some momentous changes in the Chinese way of science. In the tradition of earlier national science development efforts, including the 12 year plan of the 1950s and the subsequent *liangdan yixing* program, the MLP expresses the need for a national mobilization of effort (*juguo tizhi*) and strong government leadership to achieve scientific and technological development. However, in important respects, the MLP differs from earlier efforts, most notably in the attention it gives to stimulating the innovative capabilities of Chinese companies and giving them support to succeed in international market competition.

The MLP includes a statement of goals for the country towards 2020, proposes a series of new national R&D projects linked with existing programs, initiates a series of new "megaprojects," and introduces a variety of implementing policies intended to help

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[86] Denis Fred Simon and Cong Cao, *China's Emerging Technological Edge: Assessing the Role of High-End Talent,* p. 52
[87] Denis Fred Simon and Cong Cao, *China's Emerging Technological Edge: Assessing the Role of High-End Talent,* p. 52
[88] Yojana Sharma, "China: Ambitious 'Innovation Society' Plan," *University World News*, October 3, 2010. http://www.universityworldnews.com/article.php?story=20101002093207698

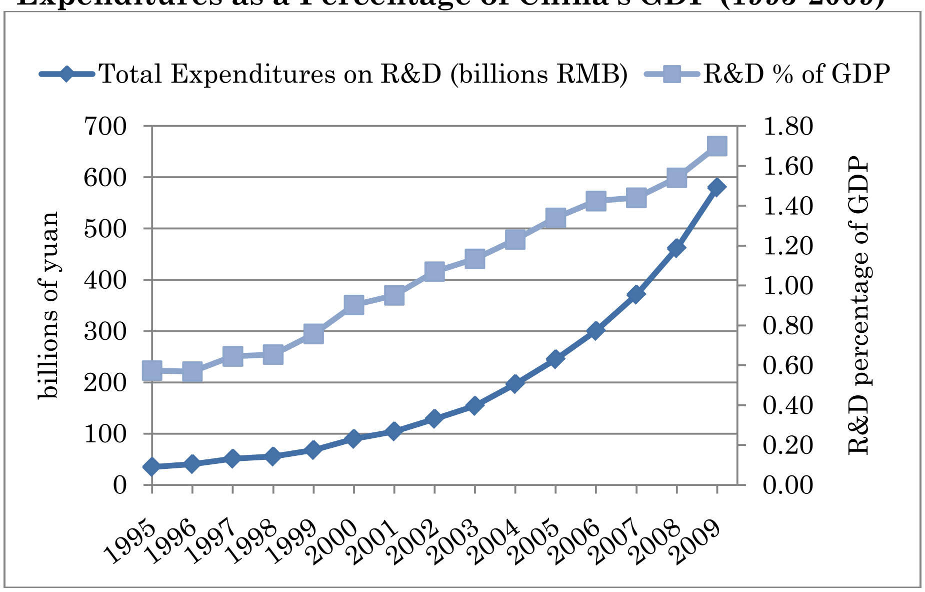
realize the goals.[89] As such, it is an attempt to pull together and better integrate the national programs of the past, significantly raise their funding, and develop an integrated policy framework—including a "web of industrial policies"—to support the idea of "indigenous innovation."[90]

Goals

The broad objectives of the MLP are to create an "overall well-off society" (*quanmian xiaokang shehui*) by 2020,[91] one characterized by a high degree of innovative capabilities. The MLP offers numerous quantitative measures of success. Objectives tied to this goal include:

- Raising overall national R&D expenditures to 2.5 percent of China's GDP by 2020, up from 1.34 percent in 2005 and 1.7 percent in 2009, as shown on the graph in Figure 8 below.[92]

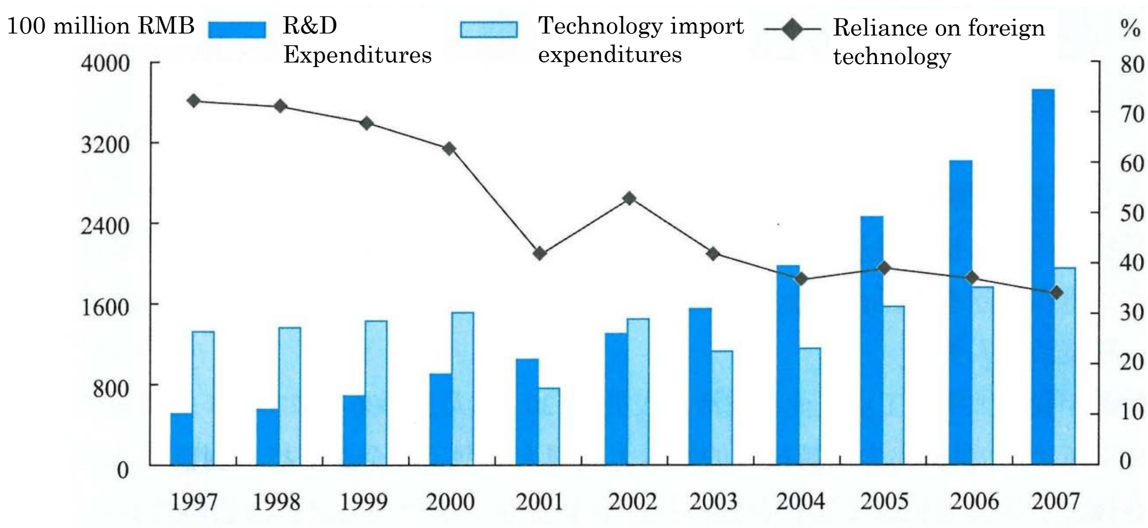
Figure 8: PRC National R&D Expenditures and Expenditures as a Percentage of China's GDP (1995-2009)[93]



[89] Cf., Liu, 2009, p. 21. See also, Sylvia Schwaag Serger and Magnus Breidne, "China's Fifteen-Year Plan for Science and Technology: An Assessment," *Asia Policy* 4 (July, 2007); and Cong Cao, Richard P. Suttmeier, and Denis Fred Simon, "China's 15 Year Science and Technology Plans," *Physics Today*, December 2006.
[90] James McGregor, "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies," US Chamber of Commerce, 2010. Available at http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies
[91] One measure of which is a per capita income of $3000, up from $1000 in 2002.
[92] The National Bureau of Statistics broadly describes R&D expenditures as falling into three standard categories—basic research, applied research, and testing and development, without further detailed definition. Funding sources and end-users are also described, as shown in the funding matrix provided in Figure 2 above.
[93] National Bureau of Statistics, Ministry of Science and Technology, *China Statistical Yearbook on Science and Technology: 2009*, Beijing. China Statistics Press, 2009. statistical data CD, Section 1-8.

- Reducing China's dependency on foreign technology to less than 30 percent in 2020.[94] Chinese statisticians measure "foreign technology dependency" as the ratio of "technology imports" to the total of technology imports plus national R&D expenditures. According to Chinese statistics, the nation is well on its way to meeting its 30 percent target. In 2007, with annual R&D spending rising to 371 billion RMB, and technology imports at $25.42 billion (~190 billion RMB), "foreign technology dependency" equaled about 34 percent, much lower than the 70 percent dependency in 1997 (see Figure 9).[95]

Figure 9: R&D Expenditure, Foreign Technology Expenditures, and Chinese Dependency on Foreign Technology (1997-2007)[96]



- Enter the world's top 10 countries in terms of citations of its professional science papers. By 2008, China had already achieved this goal, ranking 5th in in for number of papers published in the Science Citation Index (SCI) (with 570,000) from 1998-2007, and 10th in terms of the number of citations of its papers (2.6 million) in that period. This represented a dramatic increase from previous years. Papers published over this time period are shown in Figure 10.[97]

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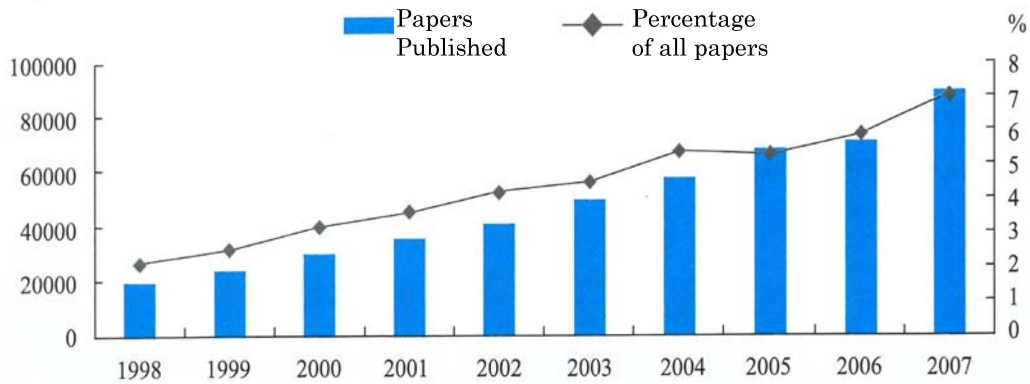
[94] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 87.

[95] China's technology imports are defined as 1) fees for licensing or purchase of exclusive technology rights ($8.59 billion, 33.8 percent of total in 2007); 2) imports of complete industrial plants, key equipment, and production lines ($6.63 billion, 26.1 percent of the total); and 3) technical data and services ($6.49 billion, 26.5 percent of total). China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 87.

[96] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 87.

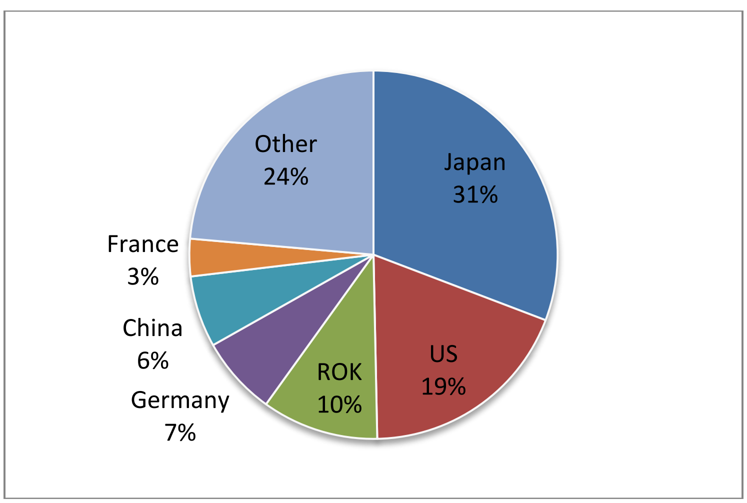
[97] The United States, by comparison published 2,974,344 papers and had 44,669,056 citations during the same time span. The value of using these numbers as a judge of Chinese scientific prowess must be tempered by reports of significant levels of plagiarism and falsified data in published papers, described

Figure 10: Chinese Papers in the Science Citation Index (1998-2007)[98]



- Joining the top 5 countries in terms of invention patents granted annually. In terms of global patents granted (and recorded by the World Intellectual Property Organization), China is already fifth in the world, with 6% of the global total, behind Japan, the United States, South Korea and Germany. At this point, many of the patents Chinese hold are less rigorously scrutinized domestic patents, and China will continue efforts to increase the number of foreign patents held by its citizens and companies.

Figure 11: Patents Grants by Country of Origin (2008)[99]



above. China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 62.

[98] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 62.

[99] *World Intellectual Property Organization, "World Intellectual Property Indicators 2010"*
, September 2010. http://www.wipo.int/ipstats/en/statistics/patents/

- Making China's economy increasingly knowledge-based, including by 2020 having technological change, as opposed to labor and capital inputs, account for some 45 percent of the economy's value.

R&D Projects

The MLP calls for an unprecedented mobilization of resources for R&D projects in 11 "priority fields," eight areas of "frontier technology," and another eight areas of "cutting-edge science" challenges further broken down into 68 priority themes. This unwieldy list is the result of a protracted committee-led drafting process, but it serves as a useful guide to the thinking of China's policymakers and scientists about the areas deserving significant investment and support for achieving its economic, social and strategic goals.[100] China's desire to develop scientific and technological capabilities in this many areas is perhaps an ambitious task, but is characteristic of a nation that aspires to be a global science and technology power.

11 "priority fields"	***Eight areas of "frontier technology"***	***Eight areas of "cutting-edge science"***
• agriculture • energy • environment • information technology and modern services • manufacturing • national defense • population health • public security • transportation • urbanization and urban development • water and mineral resources	• advanced energy • advanced manufacturing • aerospace and aeronautics • biotechnology • information technology • lasers • new materials • ocean technologies	• cognitive science • structure of matter • core mathematical themes • Earth system processes and resources, environmental and disaster affects, chemical processes • life processes • condensed matter • new approaches to scientific experimentation and observation • research technologies.

The MLP also highlights four major areas of research in basic science:

- developmental and reproductive biology
- nanotechnology
- protein science, and
- quantum research

[100] Liu Li, "Research Priorities and Priority-Setting in China" (*Vinnova:* November 2009), p. 32.

This formulation of national research needs set the stage for the expansion of China's national R&D programs, and informs the types of projects that are now being supported through the Key Technologies Program, the 863 Program, and the 973 Program.

The National Megaprojects

A central objective of the MLP is to build and strengthen the national innovation system and a capacity for "indigenous innovation" (*zizhu chuangxin*). In the view of China's scientific planners, this requires that Chinese industrial enterprises replace government research institutes and universities as the center of the national innovation system. As a result, while the MLP builds on and enhances MOST's national funding programs, Chinese companies are the beneficiaries of policy preferences and funding to an extent not seen before.

A signature feature of the MLP, which has been a source of considerable controversy, is the introduction of 16 National Megaprojects. These are China's vanguard programs for utilizing technological development to launch China into a competitive position in knowledge based, high value-added fields of industry. The program aims to harness science and technology to achieve "leapfrog development" in key areas of high technology, including in electronics, semiconductors, telecommunications, aerospace, manufacturing, pharmaceuticals, clean energy, and oil and gas exploration. The megaproject programs aim to integrate enterprises, institutes and universities in collaborative research efforts, and to promote human resources, patenting and standard-creation strategies within companies.[101] The megaprojects are divided into civilian and military projects, and clearly, some of the products of this work are beginning to show up in Chinese commercial and national security technologies.[102]

The 16 megaprojects proposed in the MLP are the following:

1) Advanced numerically-controlled machine tools and basic manufacturing technology
2) Control and treatment of AIDS, hepatitis, and other major diseases
3) Core electronic components, including high-end chip design and software
4) Extra large-scale integrated circuit manufacturing
5) Drug innovation and development
6) Genetically modified organisms
7) High-definition earth observation systems
8) Advanced pressurized water nuclear reactors and high-temperature gas cooled reactors
9) Large aircraft
10) Large-scale oil and gas exploration
11) Manned space, including lunar exploration

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[101] Ministry of Science and Technology, "Mega-projects of Science Research for the 10th Five-Year Plan." http://www.most.gov.cn/eng/programmes1/200610/t20061008_36198.htm
[102] *Xinmin Wang*, "Wo guo 6000 yi yuan keji zhongda zhuanxiang tiqian qidong (China will start early with national investment of 600 billion yuan in the science megaprojects)," February 12 2009. http://news.sina.com.cn/c/2009-02-12/011617195567.shtml

12) Next-generation broadband wireless telecommunications
13) Water pollution control and treatment[103]
14-16) Three unannounced projects, thought to be classified.[104]

The megaprojects aim to be the driving force of a new science policy and to unite China's technology and industrial policymaking. An inter-agency process overseen by a Megaprojects Leading Small Group selects program goals in the various megaproject areas, while the programs are supposedly coordinated by a special megaprojects office in MOST. However, unlike established national programs controlled exclusively by MOST, multiple agencies are involved, including NDRC, the Ministry of Finance (MOF), the Ministry of Industry and Information Technology (MIIT), and the Ministries of Agriculture and Public Health.[105] For the information technology megaproject, for instance, MIIT has been assigned responsibility for implementing the programs, while MOST is serving as a "leading" office.[106] Partially aimed at providing better oversight over program funds, this type of interagency process represents the transfer of some influence over S&T initiatives and funding to agencies that oversee industries, as well to NDRC and MOF, which have an eye towards the national macroeconomic and budgetary picture.

Implementing the MLP and megaprojects

The actual level of government and total investments related to the MLP and megaprojects remains difficult to ascertain through Chinese disclosures. China's 4 trillion RMB stimulus package, introduced in 2008 to combat the global financial crisis, accelerated funding for the projects. Of the stimulus, 160 billion RMB was committed to support "indigenous innovation" projects, including 27 billion RMB to accelerate three megaproject programs, those in core electronic devices, semiconductors, and wireless broadband, with additional funding to accelerate others.[107] In May 2009, the State Council decided to invest 32.8 billion RMB that year and an additional 30 billion RMB for

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[103] Liu Li reports that China's contribution to the ITER nuclear fusion project was rejected as a megaproject, but is now being funded at a megaproject level. In addition, a proposal to promote scientific literacy through a national action plan was also rejected from the list of 16, but is now being initiated. Liu Li, "Research Priorities and Priority-Setting in China" (Vinnova*:* November 2009), pp. 30-31; MOST, *zhongguo kexue jishu fazhan baogao 2008* (China Science and Technology Development Report 2008), kexue jishu wenxian chubanshe, September 2009, pp. 54-66.
[104] James McGregor. "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies."US Chamber of Commerce, 2010, 16. http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies
[105] *Jingji Ribao*, "Jiakuai shishi guojia keji zhongda zhuanxiang: peiyu fazhan zhanluexing xinxing chanye: quanguo zhengxie fuzhuxi, keji bu buzhang Wang Gang" (Speed Up the Implementation of the National Megaprojects: Nurture the Development of Strategic Newly-Emerging Industry: CPPCC vice-chairman, MOST Minister Wang Gang), April 28, 2010. http://www.nmp.gov.cn/gzdt/201005/t20100512_1264.htm
[106] MOST, "Hexin dianzi qijian, goaduan tongyong xinpian ji jichu ruanjian chanpin" (core electronic devices, advanced general use microchips and basic software products." http://www.nmp.gov.cn/zxjs/hgj/.
[107] James McGregor. "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies," US Chamber of Commerce, 2010, p. 17. http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies

2010 in 11 of the megaprojects.[108] Premier Wen Jiabao also announced in 2009 that there would be 600 billion RMB in investments for 6 megaprojects over an unstated period of time, and without making clear what share of that would be government investments.[109] Megaproject funds are not furnished exclusively by the central government. Rather, the megaprojects seek to bring about "multi-channel investment" from local governments, financial institutions, and enterprises themselves to stimulate a rise in R&D expenditure across the economy and to ensure that funds are directed where there is a demand.[110]

The MLP's policy guidance and plans for R&D expansion have been followed by more than 70 supporting and implementing policies intended to enhance the capabilities of the national innovation system.[111] These include: increased science and technology investments; tax incentives (for instance, generous R&D tax credits permit enterprises to deduct between 50 percent and 150 percent of their R&D expenditures) and other financial supports; public-sector procurement favoring Chinese-produced products; support for technology absorption and reengineering of imported technologies; policies to support technical standards, intellectual property development, the talent pool development, education and popularization of science, and research infrastructure; and new approaches to policy coordination.[112] As discussed later in this report, a number of these support policies have attracted considerable international attention and have led to serious controversy between foreign entities and the Chinese government because they create barriers to trade inconsistent with international norms.

The MLP has been in effect for a little over 4 years, and has been implemented under the 11th Five Year Plan. China is set to launch its 12th Five Year Plan in early 2011, which will likely bring some new directions that require adjustments in MLP implementation, particularly since new policies have recently been developed—such as one to support "emerging strategic industries," discussed below.[113]

Not everyone in China is swayed by the present direction of government policy. As the MLP has come into force, dissent from the tenets of the national planning model are evident in several camps. Their criticisms call into question the Chinese government's

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[108] MOST, "Mega-projects of Science Research for the 10th Five-Year Plan" http://www.most.gov.cn/eng/programmes1/200610/t20061008_36198.htm; Liu Li, "Research Priorities and Priority-Setting in China" (Vinnova*:* November 2009), p. 50

[109] *Xinmin Wang*, "Wo guo 6000 yi yuan keji zhongda zhuanxiang tiqian qidong (China will start early with national investment of 600 billion yuan in the science megaprojects)," February 12 2009. http://news.sina.com.cn/c/2009-02-12/011617195567.shtml

[110] National Megaprojects website, www.Nmp.gov.cn/zxjs/hgj

[111] For a useful discussion, see OECD, Annex F. p. 613 ff. Responsibility for developing the support policies has been divided up among different ministries. NDRC has been tasked with 29, the Ministry of Finance with 25, MOST was 17, and the Ministry of Education with nine. Liu Li, "Research Priorities and Priority-Setting in China" (Vinnova*:* November 2009), p. 26.

[112] James McGregor. "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies," US Chamber of Commerce, 2010, p. 16. http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies

[113] Yu Dawei, "Wan Gang: Zhongguo guojia chuangxin nengli jiejin zhongdeng fada guojia shuiping," (Wan Gang: China's Innovation Capacity Nears the Level of middle-developed nations), *Caixin* via Hexun. http://news.hexun.com/2010-11-06/125472680.html

approach to innovation. Some prominent economists, for instance, argue that China had done very well in acquiring well-tested technology from abroad, applying it to Chinese industry and agriculture, and achieving rapid economic growth. In this view, supporting new, major national R&D programs wastes national resources. Instead, China should continue to rely on technology available in the international system where opportunities for technological enhancement are still readily available via technology transfers.

From a different perspective—that of selected scientists in China and a number of ethnic Chinese scientists working abroad—Chinese national plans tend to produce derivative research and do not significantly advance the objective of making China a center for original technologies. China, instead, should rely more on policies and procedures that would stimulate curiosity-driven creative research proposals "from the bottom up."[114]

China's top-down national science programs do provide benefits in terms of stimulating advances in research, but these benefits must be tempered by an understanding of their limits in supporting innovative discoveries and commercializing results. This dynamic can be identified in China's support for nanotechnology research, described in a case study below.

Case Study I - Nanotechnology: Cutting-Edge Science and the Future of Innovation in China

Can China climb the innovation ladder and compete with the United States and other advanced nations in the most cutting-edge and complex frontiers of science with the innovation system currently in place? Nanotechnology is an area in which the PRC is focused on demonstrating that its model of top-down state-sponsored science, bolstered increasingly by linkages to industry and international scientific networks, can succeed.[115]

Nanotechnology involves controlling matter the size of molecules in order to imbue materials with unique attributes. Nanotechnology has provided modest advances in existing products (solar cells, foldable display screens, and fabrics among them), but its future applications are potentially revolutionary. Nanotechnology may one day help to identify cancerous cells, enable clean and renewable power, build high-density memory devices, raise crop yields, make self-healing materials, and detect toxins.[116] A nanotechnology "materials revolution," Chinese experts attest, will affect sectors as diverse as construction, chemicals, petroleum, automobiles, telecommunications, and

[114] Cong Cao, Richard P. Suttmeier, and Denis Fred Simon, "China's 15 Year Science and Technology Plans," *Physics Today,* December 2006.
[115] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century," *State of Innovation: The U.S. Government's Role in Technology Development* Fred Block and Matthew R. Keller. eds. (Boulder,CO: Paradigm Publishers, 2010). pp 217-235.
[116] John F. Sargent, "Nanotechnology: A Policy Primer," *Congressional Research Service*, March 12, 2010.

military systems.[117] With nanotechnology potentially one of the next drivers of economic growth, the United States, Japan, Germany and China have all lavished significant resources on the technology's development. By attaining first-mover advantage these nations hope to capture the economic and strategic benefits of being the leader in a new technological frontier.[118]

Chinese scientists began basic research in nanotechnology in the 1980s. By the late 1990s, Chinese policymakers saw nanotechnology as an opportunity ripe for leapfrog development and were determined to make China a leader in the field.[119] In 2006, Chinese officials designated nanotechnology one of its four major programs in basic science in the MLP and mobilized the bureaucracy to support and fund multiple science programs to drive its development. As a result, the government now supports nanotechnology R&D at some 50 universities, 20 CAS institutes, and a handful of government incubation centers, with several hundred enterprises also involved.[120]

By some measures, China has achieved impressive advances in nanotechnology. It ranks second behind the United States in the total number of nanotechnology journal publications annually and leads the world in such areas as the design and manufacture of carbon nanotubes.[121] Some CAS institutes and top universities are conducting work at the international frontier of the field. Yet, overall impact falls short of the achievements of China's favored elite institutions. Based on the relative impact of Chinese publications, and the relative dearth of patents by Chinese business, China is seen as being in a follower group of nations with regards to nanotechnology—alongside Japan and South Korea—but behind the US and some European countries.[122]

Lux Research estimates that the Chinese government spent $250 million in 2005 on nanotechnology, adjusted for purchasing power parity, second only to the United States.[123] A group of academic researchers more conservatively estimated that China spent $400 million from 2002 to 2007, although they expected investment to rise

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[117] *Xin Caifu*, "Nami ye zaisheng" (nanotech also rising), July 23, 2010. http://news.chinaventure.com.cn/1/20100723/40277.shtml.
[118] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."
[119] Rachel Parker, "Leapfrogging Development Through Nanotechnology Investment: Chinese and Indian Science and Technology Policy Strategies," p. 427.
[120] Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology in China," April 2008, p. 2. Subsequently published in *Asian Business & Management* 8 (2009): 461-489.
[121] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."
[122] China has also shown itself to be weak in securing international patents in nanotechnology. Of nanotechnology patent grants from the European Patent Office from 1990 to 2005, 35 percent of nanotechnology patents were made to US entities, with only 1 percent to Chinese entities. The wide disparity may also be a result of particular strategies by inventors, but this gap will surely have to close if China is to become a world leader in the field. Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, pp. 2-3, 7-9.
[123] Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, p. 5.

considerably in coming years.[124] The US still leads the global pack, spending $1.53 billion on nanotechnology in 2009, a quarter of all worldwide spending.[125]

With nanotechnology in its infancy and commercial payoffs thought to be more than a decade away, governments naturally play a key role in supporting innovation. Still, China's innovation approach differs from that of the United States and other advanced nations. The US Government supports basic nanotechnology research but plays little role in the commercialization of these technologies.[126] China, which has a weaker private sector and fewer private sources of capital than the US, provides support for scientific research through national programs, and is also building a significant apparatus to aid nanotechnology commercialization.[127]

The State Apparatus for Nanotechnology Research and Commercialization

The PRC's science policy bureaucracy sets nanotechnology goals, plans approaches, funds projects and facilitates domestic and international research collaboration. Major planning for nanotechnology began in the late 1990s, around the same time that other nations were also gearing up to support nanotechnology development. In November 2000, China established the National Steering Committee for Nanoscience and Nanotechnology (NSCNN), chaired by MOST and involving the Ministry of Education (MOE), the National Natural Science Foundation of China (NSFC), CAS, the Chinese Academy of Engineering (CAE), and the State Planning Commission, the predecessor of NDRC. Together, they jointly analyzed the future of nanotechnology and formulated an Outline for National Nanoscience and Technology Development (2001-2010), which called for a mix of funding and management for "frontier scientific problems" and for technologies with immediate applications.[128]

China's nanotechnology resources are devoted to the government's priorities of resolving key challenges the areas of agriculture, environment, population, health, and

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[124] Alexis Madrigal, "The Chinese Government's Plans for Nanotechnology," *Wired*, February 17, 2008. http://www.wired.com/wiredscience/2008/02/the-chinese-gov/

[125] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."

[126] Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, pp. 37-8.

[127] The structure of nanotechnology publications and patents shows that China's R&D effort is more heavily concentrated in universities and research institutes. From 1990 to 2006, 58.6 percent of patents from China's State Intellectual Property Organization (SIPO) were produced by academic and government research institutes with 18.7 percent for industry, and the rest by individuals. In the US, by comparison, 51 percent of its patents were developed in the commercial sector. In China, 80 of the top 100 patent assignees were universities or research institutions, revealing the small-scale of most Chinese nanotechnology enterprises. Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, pp. 8-9.

[128] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century." Working Draft, p. 22; and Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, p. 4; *Guojia Nami Keji Fazhan Gangyao 2001-2010* (Outline for the Development of Nanotechnology Science 2001-2010, September 2001. http://gongguan.jhgl.org/info/showinfo.asp?id=193

national defense.[129] The PRC government is also eager to show near-term results from nanotechnology research, including in nano-materials for the energy sector, environmental protection, and bio-medicine.[130] Projects that receive funding are often those that seem to offer immediate payoffs in these areas.[131] A relatively small group of leading universities and research institutes receive government funding, and China's nanotechnology accomplishments are narrowly concentrated in these institutions.[132] From 1990 to 2006, over half of China's nanotechnology publications came from CAS, Tsinghua University, the University of Science and Technology of China, Nanjing University and Peking University.[133]

The S&T bureaucracy has implemented its nanotechnology goals through various national programs. Two years after the MLP called for nanotechnology to be one of its key projects in basic science, the Chinese government selected 22 institutions to lead 29 projects with two-year funding of 262 million RMB ($38 million). Twelve of the institutes belong to CAS, the CAS-affiliated Chinese University of Science and Technology and the National Center for Nano Science and Technology (NCNST), with the rest being key universities. Those selected to lead more than one project include the CAS Institute of Chemistry, Beijing University, the CAS Institute of Physics, the National Center for Nanoscience and Technology (NCNST), and Tsinghua University.[134]

MOST is the largest individual source of funds for nanotechnology. The 863 and 973 programs fund mission-oriented projects in applied and basic nanotechnology. The National Natural Science Foundation (NSFC) provides much smaller grants of around 300,000 RMB (about $43,000). As of summer 2007, there were some 670 ongoing multi-year NSFC projects with "nano" in the title, totaling 800 million RMB ($120 million). The grants were given out over three years in such areas as nanomechanics, novel nanostructures, quantum dots, carbon nanotubes, and cancer and gene therapies.[135]

For China to become a nanotechnology leader, some sort of mechanism must be in place to move Chinese-developed technologies from lab to market. China does not yet have adequate pathways for businesses to develop based on nanotechnology

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[129] Ministry of Science and Technology, *Zhongguo Kexue Jishu Fazhan Baogao* (China Science and Technology Development Report), Kexue Jishu Wenxian Chubanshe, 2008, pp 109-110.
[130] Ministry of Science and Technology, *Zhongguo Kexue Jishu Fazhan Baogao* (China Science and Technology Development Report), Kexue Jishu Wenxian Chubanshe, 2008, p. 109
[131] Parker (2008) 18-19 and MOST Science and Technology Development Report, pp. 109-110
[132] Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, p. 7.
[133] Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, p. 7.
[134] The 973 program selected 11 projects in 2010 that had "nano" in the title. *kjc.njtu.edu.cn/news/files/94b1a486d20c4989869e0a26ca0a06c7.doc* ; Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."
[135] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."

developments.[136] The PRC's efforts over the last decade of nanotechnology infrastructure-building, however, show that Chinese officials understand the need for better market incentives and links between government research programs and industry. Central government agencies, and those of major cities and provinces, have strongly supported and bankrolled industrial projects and collaborative efforts between nanotechnology research institutes and domestic and foreign businesses.[137] Government-sponsored research and commercialization centers, listed in the chart below, are an important part of efforts to spur the growth of businesses to utilize and develop new advances in the field.

Figure 12: Nanotechnology research and commercialization centers promoted by central and local governments[138]

Founded	Institute	Funding/Founding organizations	Location	Purpose
2000	Nanotech Industrialization Base of China (NIBC)	MOST	Tianjin	Commercialization
2001	Shanghai Nanotechnology Promotion Center (SNPC)	Shanghai Science and Technology Commission	Shanghai	Plan R&D projects and promote nanotech industrialization in Shanghai
2003	National Center for Nanoscience and Technology (NCNST)	Founded by CAS, Peking University and Tsinghua University, and built by CAS and MOE[139]	Beijing	R&D base
2003	National Center for Nanoengineering	Three universities, three research institutes, three companies and SNPC	Shanghai	R&D
2005	China National Academy of Nanotechnology and Engineering (CNANE)	CAS, Peking University and Tsinghua University	Tianjin	Promote applied research and engineering of nanotechnology
2005	Zhejiang-California International Nanosystems Institute	Zhejiang Provincial Government	Zhejiang and California	Joint research and management skills transfer
2006	Laboratory for Biological Effects of Nanomaterials and Nanosafety (LBENN)	NCNST and the Institute of High Energy Physics (IHEP), CAS	Beijing	Multidisciplinary research in nanotechnology, biology, chemistry, toxicology, physics and medicine.

[136] Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, pp. 2-3.
[137] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."
[138] Source Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, 7; Parker; Asian Technology Information Program, "ATIP06.046: Nanotechnology Infrastructure in China, 2006. http://www.ist-mona.org/pdf/7_Nanotechnology_Developments_in_China.pdf; official Chinese websites.
[139] National Center for Nanoscience and Technology. http://www.nanoctr.cas.cn/jggk/jgjj/

2003	National Engineering Research Center for Nanotechnology (NERCN)	Ten shareholders, including universities, CAS institutes, corporations, and SNPC	Shanghai	R&D in information technology, sensors for security and environmental monitoring.
2006	Institute of Nanotech and Nanobionics	CAS, Jiangsu Provincial Government, and Suzhou City Government	Suzhou	R&D in nano devices and related materials, nano biotechnology, nano-bionics, and nano bio-safety technology.
2010	Nanotechnology Commercial and Innovation Base (in Suzhou Industry Park)	Suzhou Industry Park	Suzhou	One of 10 National Innovation bases of CAS, interdisciplinary research
2010	Suzhou Nanotechnology Industry Expert Consulting Committee	CAS, CAE, MOST and the Jiangsu government	Suzhou	Guide basic research and industrial commercialization

The Nanotechnology Industrial Base of China (NIBC) in the Tianjin Economic and Technological Development Area is a key incubator that MOST established in 2000 in conjunction with CAS, universities and private enterprises. It bills itself as "a government organization run by market forces." Since, according to NIBC literature, "pure state ownership does not work well for technology innovation or management" the Base helps universities and institutes commercialize their findings.[140] NIBC Entrepreneurship Investment Co. is a subsidiary vehicle for incubating new companies, acquiring existing companies and preparing IPOs. The Chinese National Academy of Nanoscience and Engineering (CNANE) was established under NIBC in 2005 to focus on R&D.

Shanghai established it own incubator in 2001, the Shanghai Nanotechnology Promotion Center (SNPC), funded by the Shanghai municipal government and NDRC, with contributions from local enterprises (under the Science and Technology Commission of Shanghai). SNPC has a 25 person staff and provides services for startups, training for scientists on nanoscale instruments, and has several university-affiliated industrial bases for the purpose of transferring research on nanomaterials and nanoparticles to the more than one hundred small and medium enterprises engaged in nanotechnology R&D in the Shanghai area.[141]

[140] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."
[141] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."

Suzhou, a city 60 miles west of Shanghai, is now developing into a leading center in nanotechnology, with ambitious plans to unite basic research and industrial commercialization. CAS vice-president Bai Chunli, a pioneer in nanotechnology who was credited with convincing the Politburo to invest in the sector in the early 1990s, assumed directorship of the newly formed Suzhou Nanotechnology Industry Expert Consulting Committee. The Committee is made up of 31 experts from CAS, CAE, MOST and the Jiangsu Provincial Government and is tasked to make preparations for the commercialization of advanced and mature nanotechnologies to be used in new materials, LED semiconductors, thin-film solar cells, organic diodes, pharmaceuticals, microscopic manufacturing and environmental monitoring equipment.[142]

In 2010, the Suzhou Industry Park announced major plans to invest 10 billion RMB ($1.5 billion) and attract an additional 50 billion RMB in outside capital in the next five years to build the Park into the premier nanotechnology center in China. The Industry Park invested in a national-level China Nanotechnology Commercial and Innovation Base and hosts a CAS nanotechnology research institute. Suzhou Industry Park aims to double its nanotechnology enterprises and scientists within three years, and according to *Xinhua*, it has already attracted 200 new businesses. The Park and the Innovation Base will focus significant resources on bio-nanotechnology, where Suzhou is highly competitive due to its Institute of Nanotechnology and Nano-bionics, established in 2006.[143]

The Chinese government also recognizes that international linkages are important to the growth of nanotechnology in the PRC. In 2005, the Zhejiang Provincial Government worked with Zhejiang University and the California Nanosystems Institute (CNSI) at UCLA to found the Zhejiang-California International Nanosystems Institute. The collaboration has allowed the institute to learn management and operations mechanisms from CNSI.[144] Starting in 2002, CAS has worked with a US company, Veeco Instruments, to run a nanometer technology center to provide Chinese researchers access to Veeco-made nanotech instruments, including atomic force and scanning-tunneling microscopes. The center also provides the Institute of Chemistry's molecular nanotech R&D division with "super-advanced" measuring and control devices.[145]

International linkages run much deeper than these formal arrangements. Ad hoc transnational research collaboration has also been developing. In 2005, US-based

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[142] "Suzhou jie hai neiwai 'zhinao' zhutui namo jishu chanye jidi xingcheng" (Suzhou utilizes experts from home and abroad to push forward the formation of the nanotechnology industry base), *Xinhua*, August 11, 2010. "http://www.js.xinhuanet.com/xin_wen_zhong_xin/2010-08/11/content_20593838.htm
[143] "Suzhou jiang touzi baiyi yuan dazao name chan ye jidi" (Suzhou will invest 10 billion yuan to establish the nanotechnology industry base), *Zhongguo huagong bao*, August 17, 2010. http://www.ccin.com.cn/ccin/news/2010/08/17/139850.shtml; "Guojia ji name jishu chanye he chuangxin jidi luohu Suzhou gongyeyuanqu," *Xinhua*, June 23, 2010. http://news.xinhuanet.com/fortune/2010-06/23/c_12253316.htm
[144] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."
[145] Alexandr Nemets, China's Nanotech Revolution, *Association for Asian Research*, August 23, 2004. http://www.asianresearch.org/articles/2260.html

researchers co-authored 293 nanotechnology papers with China-based researchers, more than the 269 co-authored with scientists in Germany, 202 with scientists in Japan, and the 195 with scientists in South Korea. This trend includes collaboration between Chinese scientists in the PRC and Chinese-born scientists who work in the United States.[146]

Can the Chinese model succeed?

Despite the recent attempts to better integrate China's nanotechnology research into private sector and international networks, Chinese scientists feel the government has not gone far enough in transforming the nanotechnology innovation infrastructure. While it is still too early to assess its level of China's success in nanotechnology, some still fear its top-down model gives too many funding decisions to bureaucrats, who may lose patience with a project before it is ready to stand on its own or who fund projects lacking merit. Funding for projects is often bare-bones or is invested according to less than rigorous criteria. Economic returns, say some scientists, and not just patriotism, will be necessary to make high-tech development succeed.[147]

One sign of a potential weakness in the innovation system is that China has done little to nurture private nanotechnology startup firms. American academics studying nanotechnology research in small and medium-sized firms in China found these corporations to be less engaged than their Western counterparts in nanotechnology patenting and lacking in sustained R&D capabilities. They primarily specialize in a few core technologies, either self-developed or licensed from R&D institutes, and occupy the low end of the value chain. Support from the government and cooperation with universities and research institutes is minimal.[148] It remains to be seen whether China's state-run commercialization centers can eventually help fill this void in the innovation system.

China may reap the benefits of its investments in nanotechnology and become a leader in the next major technological revolution. But before that can happen, China may have to make further reforms to the way it funds research programs and links R&D with entities that can market discoveries. It may also have to consider the possibility that scientific efforts must be supplemented by a larger role for the private sector.

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[146] Richard P. Suttmeier. "State, Self-Organization, and Identity in the Building of Sino-US Cooperation in Science and Technology." *Asian Perspective* 32, 1, 2008.
[147] Richard P. Appelbaum, Rachel Parker, Cong Cao, Gary Gereffi, "China's (Not So Hidden) Developmental State: Becoming a Leading Nanotechnology Innovator in the 21st Century."
[148] Source Philip Shapira and Jue Wang, "From Lab to Market? Strategies and Issues in the Commercialization of Nanotechnology," April 2008, pp. 37-8.

Science, Technology, and Industrial Policy

Rarely a week passes without headlines about the latest Chinese business to harness technological innovation to make an impact on global markets. Chinese companies in various industries—solar and wind energy, electric automobiles and telecommunications among them—are either poised to export advanced high-tech products once thought to be beyond China's technological capabilities, or have already captured significant market share abroad. For example, Chinese companies lead the world in the manufacture of solar panels and wind turbines. The battery manufacturer BYD has emerged as a serious player in the global competition to produce the automobile of the future, as well as a major producer of energy storage technologies needed for clean energy grids.[149] And telecommunications firm Huawei recently sought to become the primary equipment supplier to the US's Sprint Nextel.[150] In short, Chinese technology firms appear to be innovating at a rapid pace and—aided by the PRC government—are driving a shift in global economic power to China.

Among the factors propelling China's emergence as a techno-industrial power is its low-cost manufacturing capabilities, a huge market that allows for scalability, an export promotion strategy, and the shrewd appropriation of the best technology from the international system. The government—which offers support through national science programs and industrial policies aimed at high tech industries—is also a significant contributor to the successes increasingly enjoyed by national firms. The creation of the 2006 MLP portended a marriage of China's science and technology programs with a comprehensive industrial program supporting domestic enterprises, and recent industrial policies have carried these links forward. In fact, given the range of measures devoted to high-tech industrial policy in 2009 and 2010, it is arguably the case that the expansion of high-tech industry has now become one of China's highest policy priorities.

These new developments highlight a critical dilemma in the Chinese model of science: how to balance a tradition of state-centric scientific planning and mobilization with the need to utilize markets to promote innovation. China's emerging techno-industrial policies reflect a belief in at least some quarters of the Chinese Communist Party (CCP) that government intervention in the economy is precisely the instrument to achieve that balance. The PRC government can be the planner *par excellence*, directing industries to support broad state and social needs, but it can also use its power to create new markets and incentives to drive innovation to new heights.

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[149] It was this capability which first attracted Warren Buffet's investment in BYD. BYD has now entered into an agreement with China's Southern Power Grid for a demonstration of this technology. See Steel Guru, "BYD ink energy storage agreement with China Southern Power Grid, September 29, 2010. http://www.steelguru.com/chinese_news/BYD_ink_energy_storage_agreement_with_China_ Southern _Power_Grid/167569.html.

[150] *Until Sprint rejected them on security grounds. Joann S. Lublin and Shayndi Raice, "Security Fears Kill Chinese Bid in U.S.," Wall Street Journal, November 5, 2010.*
http://online.wsj.com/article/SB10001424052748704353504575596611547810220.html?mod=googlenews_wsj

Even after thirty-plus years of market reforms, the PRC government remains actively involved in the economy. While a decade ago such involvement was tempered by active drives toward marketization, in the last few years (and especially after the 2008 financial crisis), China has promoted policies that enhance the state's already active role in the economy.[151] The central government still engages in comprehensive economic planning, retains ownership of "strategic," "heavyweight" and "pillar" industries, and extensively supports businesses crucial to national goals.[152] China's economic development strategy has been mapped out in eleven consecutive Five Year Plans beginning in 1953 and through industry-specific development plans promulgated by relevant bureaucracies. These plans guide the application of an extensive set of measures designed to support domestic industry. In recent years, these measures have included subsidies, soft loans, income tax preferences, value-added tax rebates, trading rights restrictions, local content rules, national technical standards, government procurement regulations, and macroeconomic policy. The US-China Commission addresses many of these measures in its 2009 report to Congress, describing the ways in which China utilizes industrial policy to protect domestic enterprises at the expense of foreign companies.[153]

But as Chinese officials and the crafters of the MLP recognize, S&T policy and industrial policy pursued independently has more often than not failed to meet some critical national innovation goals. When S&T policy was isolated from industrial needs

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[151] See, for example, Barry Naughton, "Loans, Firms and Steel: Is the State Advancing at the Expense of the Private Sector?" *China Leadership Monitor*, No. 30, November 2009. http://media.hoover.org/sites/default/files/documents/CLM30BN.pdf

[152] Support of this type is a widespread practice in Chinese industrial policy of aiding companies considered critical to national economic and strategic goals. The PRC government has identified seven "strategic" industries (*zhanluexing chanye*) in which it must maintain "absolute control through dominant state-owned enterprises" and four "heavyweight" industries (*zhongdian chanye*) in which the state will remain heavily involved. "Strategic industries" identified by the PRC include armaments, power generation and distribution, oil and petrochemicals, telecommunications, coal, civil aviation, and shipping. "Heavyweight industries" identified include machinery, automobiles, information technology and construction. Pillar industries (*zhizhu qiye*)—those which the government has defined as important enough to merit support—can include those companies relevant to the national or local economy, to job creation, national defense, or technology acquisition. High technology industries described as pillar industries include aerospace, automobiles, bio-technology, computing, information technology, semiconductors, machinery, oil and petrochemicals, software, and telecommunications. China has also promoted so-called "national champions" which are typically large, capital-intensive enterprises with advanced technologies, often detached from SOE's or spun off from research institutes and universities. U.S.-China Economic and Security Review Commission, "2007 Report to Congress," November 2007, 38. http://www.uscc.gov/annual_report/2007/nov_report/section2.pdf; statement of Mr. Alan Wm. Wolff, "Hearing Before the U.S.-China Economic And Security Review Commission On China's Industrial Policy and Its Impact on U.S. Companies, Workers and the American Economy," March 24 2009, p. 7. http://www.uscc.gov/hearings/2009hearings/transcripts/09_03_24_trans/09_03_24_trans.pdf; statement George T. Haley, "Hearing Before the U.S.-China Economic and Security Review Commission On China's Industrial Policy and Its Impact on U.S. Companies, Workers and the American Economy," March 24 2009, p. 23. http://www.uscc.gov/hearings/2009hearings/transcripts/09_03_24_trans/09_03_24_trans.pdf; Barry Naughton, *The China circle: economics and electronics in the PRC, Taiwan, and Hong Kong*, Brookings Institution Press, 1997. Françoise Mengin, Cyber China: Reshaping National Identities in the Age of Information, Macmillan, 2004, pp. 170-171.

[153] US-China Economic and Security Review Commission, *2009 Report to Congress*, November 2009.

and market cues, it was rarely able to convert scientific achievements into commercialized products. Stove-piped funding for R&D through MOST's national programs often produced dead ends and frustration, as described in the previous section.

China's industrial policies, for their part, have succeeded in aiding the growth and expansion of China's corporations, but often fail to incentivize risk-taking to develop and deploy advanced technologies. Central bureaucracies and local governments have long spent heavily to encourage the development of high-tech industries, but lacking scientific support and protected from competition, they often ended up inundating the market with companies that competed at the low ends of the technological value chain.[154] Other policies have protected high-tech industries from competition, reducing their incentives to innovate.

Much of the dynamism of the Chinese economy comes either from domestic Chinese companies outside of the state sector, or from foreign invested enterprises (FIEs). FIEs still account for well over 80 percent of China's high-technology exports.[155] Agile "private" firms are able to capitalize on technology acquisition and development better than lumbering state-owned enterprises (SOE's).[156] One could argue, therefore, that China's most successful industrial innovation policy to date has been its divestment from roughly 80 percent of the formerly state-owned enterprises. It is also becoming clear, however, that the Chinese government consistently offers support for a wide array of firms, not just SOEs. Even China's privately-managed corporations benefit from—and actively cultivate—the patronage of the PRC government.

In recent years, and especially after the MLP was released, government policy has undergone a shift. Industrial policy and technology policy have become more integrated in order to enhance the innovation capacities of Chinese companies.[157] A slogan put forth in the MLP, the 11th Five Year Plan and official speeches explains the change taking place: China is to "speed up the construction of an innovation system that takes enterprises as the main part (*zhuti*), the market as guide, with commercialization and research interwoven."[158] Not only are companies to be the center of China's national innovation system under this plan, but research is to be supported with a clear focus on economic applications; research entities are to link up with firms that can commercialize advances; and the market is to drive projects rather than top-down directives from government agencies. While many science and industrial policies observe the slogan only in its breach, there is no mistaking the momentous transformation that is taking place in PRC thinking

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[154] See semiconductor case study
[155] Xing Yuqing, "China's High Tech Exports: Myth and Reality," EAI Background Brief No. 506. February 25, 2010. http://www.eai.nus.edu.sg/BB506.pdf.
[156] Some of these firms may not be officially state-owned, but be at least partially owned by government entities.
[157] Of course, many privately-managed successful technology companies may me partly owned by the government, their stake difficult to trace. As described in the USCC's 2007 Report to Congress, pp 36-9. http://www.uscc.gov/annual_report/2007/nov_report/section2.pdf
[158] Ministry of Science and Technology, "Zai Dang de Shiqi Da Baogao Zhong Hu Jintao Lun Keji yu Chuangxin" (In the Party's 17th Party Congress Report, Hu Jintao Talks about Technology and Innovation), October 16, 2007. http://www.most.gov.cn/yw/200710/t20071016_56350.htm.

about S&T policy. As a report from MOST states, the National Megaprojects program heralds a change in science policy from "technology breakthroughs as the center" to "product commercialization as the center."[159]

For MOST and other scientific bureaucracies, this has meant actively increasing funding and project support for R&D within enterprises. Overall, the government claims to have spent 13 billion RMB in R&D funding on enterprises in 2007.[160] Shortly after the MLP was released in 2006, MOST listed 103 innovation-driven companies to receive policy incentives and increased public funding for R&D. The recipients of these policies were 15 key SOEs, including such enterprises as the China Aerospace Science and Technology Corporation, 77 "private" companies and 11 "research institute businesses." In the next three to five years, a MOST official told *Xinhua*, the list would expand to about 500 firms. MOST has pledged to establish R&D centers within the companies, offer financial advice, provide technical training, and provide support for the protection of intellectual property rights. A vice-minister of the State-owned Assets Supervision and Control Administration (SASAC) said corporations working on nationally-important projects would be favored in these policies.[161]

The PRC's industrial bureaucracies, meanwhile, increasingly provide decisive support for commercial expansion and innovation in high-tech sectors. China reported that it allocated nearly 39 billion RMB to enterprises for "technology innovation" purposes in 2006. Chinese statistics claim that this represented 6.7 percent of enterprises' funding for innovation activities. That money was provided through "government allocations," (3.4 percent), "tax incentives" (2.3 percent), "policy-related loans" (0.9 percent) and "risk investment," (0.1 percent). An additional 49 billion RMB was provided for innovation activities through loans from financial institutions, including some state-owned banks. Additional sources of government funding for high tech enterprises—procurement measures, land grants, patenting support, and certain subsidies, investments, and loans—are potentially not included in these statistics, but have become more common in recent years.[162]

In newly-emerging green technologies, for example, the government's industrial ministries are actively aiding manufacturers in global competition. Solar energy panel makers received more than $20 billion in loans in 2010 from the China Development Bank, funding China's development of the world's newest manufacturing processes.[163] The government has offered tariff and tax incentives to clean energy companies, and in 2009,

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[159] Ministry of Science and Technology, *Zhongguo Kexue Jishu Fazhan Baogao* (China Science and Technology Development Report), Kexue Jishu Wenxian Chubanshe, 2008, p. 56.
[160] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 44.
[161] "China to Bolster Research in 103 selected companies," *Xinhua*, July 26, 2006. http://english.gov.cn/2006-07/26/content_346731.htm
[162] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), pp. 143-144.
[163] Jeremy van Loon, "Solarfun Proves Why Energy Investors Like Cheap, Chinese Panels," *Bloomberg*, September 17, 2010. http://www.bloomberg.com/news/2010-09-17/solarfun-proves-why-renewable-energy-investors-like-cheap-chinese-panels.html

established 16 energy R&D centers that will focus on key technologies in nuclear power, wind power, efficient power generation and transmission, and facility materials.[164] Through these and other initiatives, China has become a leader in the manufacture of renewable energy equipment.[165]

China's industrial bureaucracy also supports electric car makers. The PRC's *Global Times* reported in September 2010 that MIIT would invest 100 billion RMB ($14.7 billion) by 2012 to support the industry.[166] SASAC, which owns controlling stakes in China's automobile manufacturers, announced that a new group made up of state-owned automakers and manufacturers will promote common standards and accelerate research among state-owned companies to support the production of electric cars and their batteries.[167]

On October 10th, 2010 China announced an initiative that may herald a new phase in China's industrial policy—one that broadens the government's focus on promoting the development of technologically-heavy enterprises more than ever before. The initiative envisions mechanisms for spurring innovation on a grand scale. No longer content to see Chinese companies succeed in a few specialized areas of technology—such as green energy and transportation—the *State Council's Decision to Accelerate the Development of Strategic Emerging Industries* calls for extending support for industries in seven emerging sectors where "revolutionary breakthroughs" are possible. Sources told *Reuters* that $1.5 trillion dollars would be invested over the life of the initiative.[168] The sectors singled out for aid in the resolution are:

1) ***Energy conservation and environmental conservation***, including energy-saving equipment and products, pollution control, clean coal, and utilization of seawater.

[164] Julian Wong, "The Challenge of China's Green Technology Policy and Ohio's Response," Written testimony before the U.S.-China Economic and Security Review Commission, July 14, 2010. http://www.uscc.gov/hearings/2010hearings/written_testimonies/10_07_14_wrt/10_07_14_wong_statement.php

[165] For example, see Jason Dean, Andrew Browne, Shai Oster, "China's 'state capitalism' sparks a global backlash," *The Wall Street Journal*, November 16, 2010. http://online.wsj.com/article/SB10001424052748703514904575602731006315198.html

[166] Elaine Kurtenbach, "China Electric Car Makers Plan Standards, Research," *Associated Press*, August 19, 2010. http://www.boston.com/business/technology/articles/2010/08/19/china_electric_car_makers_plan_standards_research/

[167] Elaine Kurtenbach, "China Electric Car Makers Plan Standards, Research," *Associated Press*, August 19, 2010.

[168] Although the Decision sets targets for 2015 and 2020, the length of the initiative is not clear. Benjamin Kang Lim and Simon Rabinovitch, "China mulls $1.5 trillion strategic industries boost: sources," *Reuters*, December 3, 2010. http://www.reuters.com/article/idUSTRE6B16U920101203?pageNumber=2. *China Business News*, "China Key Industries to Grow 24% in 2011-15," December 8, 2010. http://cnbusinessnews.com/china-key-industries-to-grow-24-in-2011-15/

2) ***Information technology***, including Next-Generation Internet equipment, broadband-based information network infrastructures, the Internet of Things, cloud computing, integrated circuits, and new display devices, software and servers.
3) ***Biotechnology***, including pharmaceuticals and agriculture.
4) ***Large-scale machines***, including civilian aircraft, satellite and aerospace technology, intra- and inter-city rail transport, offshore exploration rigs, and intelligent manufacturing facilities.
5) ***Clean energy***, including nuclear, solar, wind, and smart grid technologies.
6) ***New materials***, including the development of rare earth materials, membrane materials, special glass, functional ceramics, semiconductor materials, LED materials, metal alloys and alloy steels, engineering plastics, carbon fiber, Kevlar fabrics, ultrahigh molecular weight poly-ethylene (UHMWPE); and research on nanomaterials, superconducting materials, and intelligent materials.
7) ***Electric vehicles***, including hybrids cars, pure electric cars and batteries.[169]

The *Decision to Accelerate the Development of Strategic Emerging Industries* Strategic exemplifies China's ambitions to utilize high-tech industry to restructure its economy and scale new international economic heights. The seven sectors include some in which foreign companies do not hold insuperable advantages in technology, cost, or scale—the electric vehicle, new materials and clean energy technologies, for example. Other technologies have potential national security value, such as Internet technologies and large-scale machine industries.

A crucial feature of the "strategic emerging industries" initiative is that government policymakers believe significant government funding is necessary to launch these infant industries. According to Chinese calculations, value-added in these seven sectors currently accounts for less than four percent of GDP, but China will strive to achieve value-added in these sectors of eight percent by 2015 and 15 percent by 2020.[170] Rough calculation shows that to realize these targets, the value-added from these industries must grow at an average of over 24 percent annually in 2011-2015, and over 21 percent annually in 2016-2020.[171]

According to experts with knowledge of the Strategic Emerging Industries Decision, the PRC government will pursue nuanced policies to achieve these goals, not simply isolated government injections of capital. While sources said the overall investment in these industries is slated to be $1.5 trillion, one of the plan's drafters noted that the government would provide only around "5 to 15 percent of the funds for the plan, with the

[169] State Council, "Guowuyuan Guanyu Jiakuai Peiyu he Fazhan Zhanluexing Xinxing Chanye de Jueding" (Decision to Accelerate the Development of Strategic Emerging Industries) October 10, 2010, Guofa [2010] No. 32. http://www.gov.cn/zwgk/2010-10/18/content_1724848.htm
[170] People's Daily Online, "Strategic Emerging Industries Likely to Contribute 8% of China's GDP by 2015," October 19, 2010. http://english.peopledaily.com.cn/90001/90778/90862/7170816.html
[171] istockanalyst, "China's Strategic Emerging Industries to Post 24.1 Annual Growth in 2010." December 7, 2010. http://www.istockanalyst.com/article/viewiStockNews/articleid/4727141; State Council, "Guowuyuan Guanyu Jiakuai Peiyu he Fazhan Zhanluexing Xinxing Chanye de Jueding" (Decision to Accelerate the Development of Strategic Emerging Industries) October 10, 2010, Guofa [2010] No. 32. http://www.gov.cn/zwgk/2010-10/18/content_1724848.htm

aim of encouraging private investment."[172] Actual funding may fall short of the announced objectives, however, as the government has been known in the past to use the prospect of investment to stimulate private funding.

The Strategic Emerging Industries Decision also calls specifically for:

- Expanding basic research on the critical technologies in "strategic emerging" industries;
- Increasing R&D expenditures in enterprises, and for industrial pilot/demonstration projects, and research alliances involving labs and universities led by backbone industries;
- Creating financial incentives for intellectual property development;
- Improving research environments to unleash the creative talents of individuals;
- Implementing and supporting major engineering projects to push forward technological development;
- Building improved financial and consulting support for industry; and
- Building mechanisms to aid the commercialization of technology.[173]

The government will also reportedly establish supportive policies in taxation, consumption, government procurement, corporate research and development, and recruitment. Experts involved with the plan say that the 15 percent corporate tax rate for certain high-tech companies will likely be cut in half. Some companies incorporated in China will be eligible to apply for a 150 percent tax deduction for certain R&D expenditures.[174] The government will also expand preferential treatment to high-tech companies for land acquisition.[175]

Precedents in Techno-Industrial Policy

China's efforts to link industrial policy with science and technology policy to enhance domestic industries can be seen as an attempt to popularize and broaden the methods used in earlier successes. In the telecommunications sector, "national champions" Huawei Technology Corporation and Shenzhen Zhongxin Technology Corporation (ZTE) were propelled to prominence by government support for innovation at various stages in

[172] Chong Hong-chee and Staff Reporter, "Incentive Policies Planned for Strategic Industries in China," *Want China Times*, December 7, 2010.
http://www.wantchinatimes.com/news-subclass-cnt.aspx?cid=1102&MainCatID=11&id=20101207000064
[173] State Council, "Guowuyuan Guanyu Jiakuai Peiyu he Fazhan Zhanluexing Xinxing Chanye de Jueding" (Decision to Accelerate the Development of Strategic Emerging Industries) October 10, 2010, Guofa [2010] No. 32. http://www.gov.cn/zwgk/2010-10/18/content_1724848.htm
[174] Chong Hong-chee and Staff Reporter, "Incentive Policies Planned for Strategic Industries in China," *Want China Times,* December 7, 2010.
[175] Benjamin Kang Lim and Simon Rabinovitch, "China mulls $1.5 trillion strategic industries boost: sources," *Reuters*, December 3, 2010.
http://www.reuters.com/article/idUSTRE6B16U920101203?pageNumber=2

their rise, in part because of their technology's importance to China's infrastructure and national defense. With the government's S&T funding serving as a technology "push," and government purchases and a rapidly expanding market serving as commercial "pulls," these companies succeeded in making incremental innovations that allowed them to catch-up with foreign competitors.

Today, Huawei and ZTE are global telecommunications powerhouses, and some of China's few truly successful technology-based multinational companies (some others include Lenovo, BYD, and a handful of solar and wind power equipment manufacturers). Huawei is the world's third largest telecommunications supplier,[176] and ZTE, which derives 70 percent of its revenue from outside China, is rising in the value chain, recently expanding its sales of mobile phones in the US market.[177] ZTE is a publically-traded company and Huawei claims the government has no stake in it despite an opaque ownership structure, but both have relied on various forms of government support since their inception—and both have strong links to the government and the People's Liberation Army (PLA). A former information engineering officer in the PLA, Ren Zhengfei, founded Huawei in 1988 to manufacture simple switches, often for military customers.[178] ZTE was founded in 1985 by state-owned companies affiliated with the Ministry of Aerospace Industry.[179]

According to Peilei Fan of Michigan State University, the government acted for Huawei and ZTE as "both a developmental and a laissez-faire state," providing "dynamic intervention at various stages, setting the 'advanced' demand at the beginning," and then encouraging the companies to pursue innovation independently. In the 1980s, with China importing most of its telecommunications equipment from foreign MNC's, the government sought to develop advanced indigenous equipment by allowing new companies to compete in the market against established SOEs. This policy harmed some existing manufacturers, but succeeded in stimulating public research institutes to develop and commercialize better products. China also promoted much of the early research on telecommunications equipment through R&D programs in the Ministry of Posts and Telecommunications and in the PLA.[180]

In order to overcome latecomer disadvantages, ZTE and Huawei partnered with government-sponsored research institutes to conduct R&D, including with the Posts and Telecommunications Universities of Beijing, Nanjing and Shanxi. As the companies expanded in the 1990s, the government provided them with low-interest bank loans and encouraged government telecommunications service providers to purchase indigenously-

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[176] Ariana Eunjung Cha, "Telecom Firm in China Sets Sights on U.S. Market," *Washington Post*, January 6, 2008.
http://www.washingtonpost.com/wp-dyn/content/article/2008/01/05/AR2008010502608.html
[177] Owen Fletcher, "ZTE Pushes Mobile Phones," *The Wall Street Journal*, September 22, 2010, B9B.
[178] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy* (Ithaca: Cornell University Press, 2009), p. 215-216.
[179] *Bloomberg Businessweek*, "A Global Telecom Titan Called...ZTE?" March 7, 2005.
http://www.businessweek.com/magazine/content/05_10/b3923071.htm
[180] Peilei Fan, "Catching Up Through Staged Development and Innovation: The Case of Chinese Telecom Companies," *Journal of Science and Technology Policy in China*, Vol. 1 No. 1 2010, 65-84.

made switches. By the 2000s, Huawei and ZTE had built large in-house R&D capacities, supported in these efforts by IBM, Lucent, Texas Instruments and Motorola, among other foreign firms. Huawei now says half its employees and ten percent of its revenues are committed to R&D,[181] and in this sense is an outlier from the typical Chinese enterprise which spends a relatively small portion its own funds on R&D by international standards. At the same time, ZTE and Huawei also benefited significantly from their participation in national S&T programs. For example, ZTE participated in 19 projects under the 863 Plan by 2002.

As the companies grew, the Chinese government began to reduce direct R&D support, but rallied around them to aid their global expansion. In 2004, Huawei received a $10 billion credit line from the state-owned China Development Bank and $600 million from the Export-Import Bank of China to fund its "going out" strategy. Huawei's line of credit has reportedly helped it to undercut competitors' bids abroad by as much as 70 percent.[182]

China's latest industrial policies envision a similarly successful development process for an ever-growing list of high-tech sectors. Yet, China's successes in the telecommunications field are not necessarily replicable in other sectors. Notably, China's semiconductor design and manufacturing industry has failed to achieve robust innovation despite significant government support for over a decade.

Case Study II - Techno-Industrial Policy in the Semiconductor Sector

The development and deployment of semiconductor-based information technology was the foundation of the US economy's accelerating growth in the 1990s and spurred the development of many other high-tech enterprises.[183] According to China's Ministry of Science and Technology, semiconductor technology "is a core resource in supporting the continued development of the national economy and in ensuring the nation's strategic security," and thus long a priority for China's government.[184] Because semiconductors are crucial to an information-based economy and national defense capabilities, China has sought for at least a decade to achieve success in their design and industrial production. A major State Council planning document from 2000, Circular 18, stated that China's aim was to become a leading chip design and manufacturing center by 2010. Chinese integrated circuit (IC) technology, the Circular stated, would "match most demands from

[181] Ariana Eunjung Cha, "Telecom Firm in China Sets Sight on US Market," *The Washington Post*, January 6, 2008. http://www.washingtonpost.com/wp-dyn/content/article/2008/01/05/AR2008010502608_2.html
[182] Craig Simons, "The Huawei Way," *Newsweek*, January 16, 2006, http://www.newsweek.com/id/47446
[183] Dewey & LeBoeuf for the Semiconductor Industry Association, "Maintaining America's Competitive Edge: Government Policies Affecting Semiconductor Industry R&D and Manufacturing Activity," White Paper, March 2009, p. 4. http://www.sia-online.org/galleries/default-file/Competitiveness_White_Paper.pdf
[184] National Megaprojects website, www.nmp.gov.cn/zxjs/hgi/

the domestic market and be exported in large quantities."[185] Successful international IPOs of a few Chinese semiconductor firms in the early 2000s convinced some investors that China's IC industry was poised to have a global impact.[186]

Instead, Chinese semiconductor companies have proven to be largely unprofitable and China has been confounded by the wide technological gap with leading nations.[187] Instead of exporting chips in large quantities, the PRC depends on imported chips for at least 80 percent of the electronics it produces for both domestic use and export. According to a scientist from CAS, China spends more money on microchip imports than it does importing oil.[188] Chinese semiconductor firms cannot compete with the likes of Intel, Qualcomm and Samsung in the design of computer microchips. Nor have they succeeded in establishing high-end microchip manufacturers (foundries) to challenge efficient firms like Taiwan Semiconductor.[189] While China's semiconductor industry may have accounted for as much as 10.7 percent of the worldwide semiconductor industry in 2008, Chinese IC companies are generally positioned on the low end of the global value chain, using older-generation foreign technology, toiling on peripheral products, and imitating more than innovating.[190] Chinese entities are responsible for fewer than two percent of global semiconductor patent applications.[191] And China's impressive supercomputers—ranked first and third fastest in the world in 2010—employed chips from American firms Intel and Nvidia, not Chinese chips being developed specifically for the projects in CAS institutes.[192]

Part of China's difficulty stems from its need to play catch-up in a fast-paced field. Frontrunners have a wide advantage in the IC industry because innovations in the technology are constant and highly cumulative. Firms have to be able to innovate quickly, accumulate intellectual property rights, and use profits to reinvest in R&D to fund the next round of advances. Those that fall behind see their products lose value and then

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[185] Falan Yinug, "Challenges to Foreign Investment in High-tech Semiconductor Production in China," *Journal of International Commerce and Economics*, United States International Trade Commission, web version, May 2009, 6; State Council, *guowuyuan guanyu yinfa guli ruanjian chanye he jicheng dianlu chanye fazhan ruogan zhengce de tongzhi* (State Council notification related to distributing the certain policies to encourage the development of the software and integrated circuit industry) (Circular 18), June 24, 2000. http://www.chengdu.gov.cn/news/detail.jsp?id=64387

[186] Vivek Wadhwa, "Why China's Chip Industry Won't Catch America's," *Bloomberg Businessweek*, September 3, 2009. http://www.chengdu.gov.cn/news/detail.jsp?id=64387

[187] National Megaprojects website, www.nmp.gov.cn/zxjs/hgi/

[188] Xu Ying and Jin Lin, "Zhongkeyuan yuanshi Zou Shichang: zhongguo xinpian 80 percent kao jinkou" (CAS member Zou Shichang: Chinese computer chips are 80 percent imports), *Shanghai Shangbao*, August 24, 2010. http://tech.sina.com.cn/it/2010-08-24/15574581996.shtml

[189] Xu Ying and Jin Lin, "Zhongkeyuan yuanshi Zou Shichang: zhongguo xinpian 80 percent kao jinkou"

[190] PriceWaterhouseCoopers, "China's Impact on the Semiconductor Industry: 2009 Update," p. 34.

[191] Huang Cancan, "Shi lun wo guo jicheng dianlu chanye fazhan qianjing" (On the development prospects of China's semiconductor industry), *Heilongjiang Keji Xinxi*, Vol. 21, 2010.

[192] John Markoff, "Chinese Supercomputer is Ranked World's Second-Fastest, Challenging U.S. Dominance," *The New York Times*, May 21, 2010. http://www.nytimes.com/2010/06/01/science/01compute.html; Matthew Luce, China Eyes 'Dual Use' Applications for its Supercomputers, *China Brief*, Vol. 10, Issue 23 (November 19, 2010). http://www.jamestown.org/programs/chinabrief/single/?tx_ttnews[tt_news]=37195&tx_ttnews[backPid]=414&no_cache=1

disappear entirely from the market. China's semiconductor firms have so far not been able to accommodate innovation at the speed necessary to compete with the best in the world.[193]

China's semiconductor sector is a mix of private companies, foreign-owned enterprises, state-managed SOEs, and nominally independent state-controlled firms, but the government has significant ownership stakes in most large companies.[194] To spur innovation, the government provides investment and various support mechanisms for industry players. Before China joined the World Trade Organization (WTO) in 2001, major support came largely from export subsidies. Afterwards, the government continued to provide aid through more targeted policies. By 2005, the NDRC had drafted an IC-industry support plan and selected 94 enterprises to receive R&D funding, tax advantages, personnel development support, and financing tools. The NDRC also provided project development funds for critical semiconductor facilities, and for the production of materials and consumables.[195]

Local governments also promoted the semiconductor industry as far back as 1995, as called for in China's 9th Five Year Plan. The 909 Project, for example, saw the Shanghai government invest 10 billion RMB to establish Huahong, which is now one of China's most advanced chip manufacturers. Huahong was tasked to manufacture semiconductors using 8-inch wafers[196] and it enlisted the support of Japan's NEC to manage production. Critics note, however, that by the time the project got off the ground, most advanced companies were already using 10-inch wafers in semiconductor manufacturing.[197]

Such local funding was typically spent on projects with short time horizons and minimal considerations for technological innovation. Chinese industry analysts believe that state programs meant to encourage catch-up in the semiconductor industry were often misconceived and too lumbering to keep pace with global innovation. One of China's leading chip foundries, Semiconductor Manufacturing International Corp (SMIC), spread its microchip foundries across in China to take advantage of benefits offered by local

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[193] Sungho Rho, Keun Lee, Seong Hee Kim, "Limited Catch-up in China's Semiconductor Industry: A Sectoral Innovation System Perspective," paper submitted to the Making Innovation Work for Society: Linking, Leveraging, and Learning conference, University of Malaya, Kuala Lumpur, Malaysia (1-3 November 2010), http://umconference.um.edu.my/upload/43-1/papers/129%20SunghoRho_KeunLee_SeongHeeKim.pdf

[194] *21st Century Business Herald*, "Daxiang wei wu: Bandaoti chanye zhengfu touzi yousilu" (the elephant can't move: A record of doubts in the government's investments in the IC industry) March 21, 2009. http://tech.sina.com.cn/it/2009-03-21/02462930073.shtml

[195] *Nanfang Dushi Bao,* "94 jia bandaoti qiye huoqu xin zheng fuchi (94 semiconductor enterprises get support from a new policy)," August 23, 2007. http://finance.sina.com.cn/roll/20070823/14461621871.shtml

[196] A wafer is a thin slice of semiconductor material used in the fabrication of integrated circuits.

[197] *21st Century Business Herald*, "Daxiang wei wu: Bandaoti chanye zhengfu touzi yousilu" (the elephant can't move: A record of doubts in the government's investments in the IC industry) March 21, 2009.

governments eager to support high-tech industry, only to realize too late the inefficiencies created by dispersing its operations.[198]

Funding from local governments for various competing firms also led to the inundation of certain high-tech markets, especially in integrated circuit design. Fierce price competition has strained the more than 500 (largely small) Chinese design enterprises currently in operation, and foreign observers expect a shakeout. Some design companies have already gone bankrupt. The advisory firm PricewaterhouseCoopers expects that no more than 100, and possibly fewer than 50, Chinese IC design companies will remain truly viable.[199]

The failures of the government's pure R&D efforts were perhaps even more frustrating than its techno-industrial policy. Two major instances of corruption in government science programs (described on page 33) took place through China's drive to build semiconductors. While the funds lost from such incidents were a drop in the bucket of China's R&D expenditures, they were a clear lesson to Beijing that demanding IC breakthroughs from scientists toiling in universities and national labs was not going to fulfill the government's desire for innovation.[200]

New Policy Directions, Part I: Towards Collaborative Innovation

Sobered by past failures, current government S&T plans reflect a modified approach to innovation in the semiconductor field. Leading governmental actors are attempting to consolidate the semiconductor industry while directing it slowly towards higher-end production. The government is also integrating technological development into its plans by attempting to form R&D links among domestic semiconductor firms, research organizations, universities, and foreign firms.[201] China will also seek to leverage its large domestic market, the prospect of loosening technology transfer restrictions to China, and the ability to capitalize on the steadily increasing flow of human capital to China from foreign firms and universities to increase its prospects for catch-up (further discussion of China's attempts to attract more multinational companies to establish semiconductor R&D centers in China is on page 90).

Two of China's engineering megaprojects are dedicated to semiconductor technology, including one for "core electronic devices, high-end general use microchips, and basic software products" and one for "large-scale integrated circuit manufacturing equipment and comprehensive technology."[202] These were two of the earliest megaprojects to have entered the implementation stage.

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[198] *21st Century Business Herald*, "Daxiang wei wu: Bandaoti chanye zhengfu touzi yousilu" (the elephant can't move: A record of doubts in the government's investments in the IC industry) March 21, 2009.
[199] PriceWaterhouseCoopers, "China's Impact on the Semiconductor Industry: 2009 Update," p. 52.
[200] Wu Zhong, "Two Chip Scandals Set Back China's IT Industry," *Asia Times*, July 4, 2006, http://www.atimes.com/atimes/China_Business/HG04Cb06.html
[201] Sungho Rho, Keun Lee, Seong Hee Kim, "Limited Catch-up in China's Semiconductor Industry: A Sectoral Innovation System Perspective."
[202] National Megaprojects website. www.nmp.gov.cn/zxjs/hgi/

The megaproject implementation plans for the IC industry are oriented towards achieving advances in government-determined scientific areas. MOST has outlined the technologies it hopes to pursue in the short term through the megaprojects: Chinese chips for use in supercomputers, competitive system on chip (SoC) products, and a central processing unit/operating system (CPU/OS) for a Chinese-made computer to be used for "security" purposes. Over the long-term, MOST will direct R&D to "general high-performance central processing units (CPUs), digital signal processing (DSP), system on chip (SoC) and development platforms, IP core design, and electronic design automation (EDA)."[203]

The megaprojects incentivize industry R&D labs, universities and research institutes to work together, augmenting each others' strengths and pooling their resources on technological challenges. By the beginning of 2010, the integrated circuit manufacturing megaproject consisted of nine programs involving 25 entities – manufacturers, R&D institutes and universities—and claims to have created the country's first "commercial indigenous innovation alliance."[204] The programs have directly supported industrial projects initiated in the 10th and 11th Five Year Plans, and have emphasized support for "backbone industries" in semiconductor manufacturing.[205]

The government also promotes certain areas of technology in which it believes China to have a comparative advantage, most notably LED integrated circuit technology. Local governments are particularly active in trying to attract research money and talent for these projects. One example of such efforts was the Jiangsu Provincial Government's support for a "strategic innovation alliance" in 2010 involving 61 enterprises, research institutes and universities to conduct R&D on LED semiconductors. Yangzhou in Jiangsu, a major center for the LED industry, was also given a boost when MOST chose it as one of ten cities to receive subsidies to produce LED products.[206]

Interdisciplinary research institutes are playing a growing role in closing the gap between R&D and product commercialization. In 2002, for example, the non-profit Shanghai Integrated Circuit Research and Development Center was established. The center was financed by Huahong Group, Fudan University, Shanghai Jiaotong University, Guangdong Normal University and Shanghai Beiling, and receives support from the Shanghai government. The center conducts R&D in initial process technologies and facilitates the application of technology to mass production for Huahong-NEC foundries.

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[203] Ministry of Science and Technology, *Zhongguo Kexue Jishu Fazhan Baogao* (China Science and Technology Development Report), Kexue Jishu Wenxian Chubanshe, 2008, pp. 55-56.
[204] MOST Megaprojects Office. "Guojia keji Da Zhuanxiang Gongzuo Jianbao" (Work report on the National Megaprojects, January 6, 2010 Vol. 1 (Overall Vol. 89).
http://www.nmp.gov.cn/gzjb/201004/t20100407_1245.htm
[205] Ministry of Science and Technology, *Zhongguo Kexue Jishu Fazhan Baogao* (China Science and Technology Development Report), Kexue Jishu Wenxian Chubanshe, 2008, pp. 57, 65; Ministry of Commerce, PRC.
http://english.mofcom.gov.cn/aarticle/newsrelease/commonnews/201008/20100807102681.html
[206] *Zhongguo Gaoxin Jishu Chanye* Daobao, "Jiangsu 61 Jia Qiye he Kexue Yanjiuyuansuo Jie Bandaoti Zhaoming Chanye Lianmeng (61 Jiangsu enterprises and research institutes create an IC LED alliance," August 16, 2010. http://tech.sina.com.cn/it/2010-08-16/16314550378.shtmlhttp://www.alighting.cn/special/20090422/index.htm

Its researchers also have opportunities to engage in international cooperation through Europe's Interuniversity Microelectronics Center. The center has plans for a major personnel expansion in the coming years.[207]

New Policy Directions, Part II: Supporting IC Enterprises

Along with the growth in government-supported scientific links between R&D entities and enterprises, industrial policymakers are promoting top-down plans they claim will build a stronger IC industry. The government intends to spend more money, consolidate firms, and support the launch of startups. Rather than heralding an embrace of private firms, these policies suggest that the state sector may be advancing and consolidating its control over the market.

The government plans to increase funding for the IC industry substantially in coming years. According to SEMI, a global semiconductor industry organization, the Chinese government has spent $7 billion in new fabrication plants since 2004 and the funding spigot is about to get much larger. There are plans for $50 billion more in government investment by 2020, with local governments expected to contribute $20-$25 billion in the next five years and the central government expected to invest $30 billion in the next fifteen years.[208]

The Ministry of Industry and Information Technology (MIIT), which has responsibility for regulating China's IT sector, has promoted an ambitious plan to restructure the IC industry to become globally competitive in all aspects of chip production—from the lower-end manufacturing, packaging and testing of chips that constitutes most of the Chinese IC industry, to the cutting-edge design of computer microchips. The 11th Five Year Plan also calls for expanding China's semiconductor industry in all areas while emphasizing the need to expand the proportion of the industry focused on design. MIIT hoped to have design expand from 17.7 percent of China's IC industry in 2005 to 23 percent of the industry in 2010. The 11th Five Year Plan also called for expanding domestic supply of China's integrated circuit needs from 16 percent during the 10th Five Year Plan to 30 percent by 2010,[209] and raising China's global share of chip design to between 8 and 10 percent from 6 percent in 2008.[210]

The 11th Five Year Plan includes specific industry targets to reach these goals. It calls for developing five semiconductor design companies each worth three to five billion

[207] Sungho Rho, Keun Lee, Seong Hee Kim, "Limited Catch-up in China's Semiconductor Industry: A Sectoral Innovation System Perspective;" and http://www.asia-invest.de/select-it/en/participating/icrd/index.html

[208] SEMI, China Market Growth Fueled by Government Spending during Industry Downturn. http://www.semi.org/en/MarketInfo/ctr_027596?id=highlights

[209] MIIT Comprehensive Planning Office, "'Jicheng Dianlu Chanye Shiyiwu Zhuanxiang Guihua' Jiedu" (Analysis of 'Projects in the Integrated Circuit Industry the 11th Five Year Plan'), January 17, 2008. http://www.sica.org.cn/newEbiz1/EbizPortalFG/portal/html/InfoContent.html?InfoPublish_InfoID=c373e916b6d4ff098feaa2644ab9fb7c

[210] Ministry of Science and Technology, *Zhongguo Kexue Jishu Fazhan Baogao* (China Science and Technology Development Report), Kexue Jishu Wenxian Chubanshe, 2008, pp. 55-56.

RMB ($432 million to $719 million) and ten companies each worth one to three billion RMB ($144 to $432 million) by the end of 2010. Such policies have often involved the government consolidating its control of the industry, using state-backed firms to take over smaller industry players.

The Shanghai government has already engineered the mergers of some of China's largest chip manufacturers under its control in order to integrate operations and boost their R&D capacity.[211] At the same time, however, local governments across the country continue to promote policies—including new subsidies to local pillar industries—that are inundating the IC manufacturing market, according to a report in China's *21st Century Business Herald*.[212] These policies are seemingly at odds with the Shanghai government and MIIT's goal of consolidating IC firms.

In one small sign of support for a private-sector solution to innovation, China is stepping up efforts to nurture smaller innovative companies, seeding as many as 30 fabless (design-only) semiconductor start-ups expected to take in revenue of $200 million. A portion of China's 2009 stimulus package was also earmarked for grants, loans and equipment for such startups.[213] Through 2012, the government will also provide incentives to encourage local semiconductor manufacturing suppliers to develop front-end and back-end 65-90 nanometer equipment.[214]

Even as the government pursues ambitious new plans, the semiconductor sector illustrates the difficulty of matching the rapid pace of innovation of the world's top companies through government intervention. In an environment of fast-paced innovation, it is still unclear whether government policies will truly address bottlenecks in innovation rather than squander resources best used in other ways. The government has yet to prove that its latest strategy will enable China's IC firms to scale new technological heights and create new markets, rather than waste money on a daunting quest to create national semiconductor champions that are internationally competitive.

Implementing China's Industrial Ambitions

Four and a half years after the MLP called for science policy to focus on stimulating innovation capacity within enterprises, Chinese planners and politicians are still wrestling with implementation of their strategy. The role of technological development in industrial policy will be front and center as the government forges

[211] *21st Century Business Herald*, "Daxiang wei wu: Bandaoti chanye zhengfu touzi yousilu" (the elephant can't move: A record of doubts in the government's investments in the IC industry) March 21, 2009. http://tech.sina.com.cn/it/2009-03-21/02462930073.shtml
[212] *21st Century Business Herald*, "Daxiang wei wu: Bandaoti chanye zhengfu touzi yousilu" (the elephant can't move: A record of doubts in the government's investments in the IC industry) March 21, 2009.
[213] PriceWaterhouseCoopers, "China's Impact on the Semiconductor Industry: 2009 Update," p. 55.
[214] Lily Feng, "Opportunities Abound in China's Semiconductor and Solar Industries," SEMI http://www.semi.org/en/MarketInfo/ctr_028015?id=highlights

economic goals and determines economic projects for the next half-decade in its 12th Five Year Plan, to be publicly released in 2011. Certain patterns have already emerged. In the telecommunications and semiconductor sectors describe above, techno-industrial policy has included:

- Government support for industry-institute collaborative R&D efforts
- Loans from state banks
- Direct investments in high-tech industry by central and local authorities
- Consolidation of industries through acquisitions by state-owned and -invested companies

Other commonly-used industrial measures include the construction of technology development zones, the use of government procurement, and the promulgation of national standards.

Technology Development Zones

Having witnessed the success stories of Hsinchu Science Park in Taiwan and Silicon Valley in the United States, Chinese technocrats have tried to mimic these incubators in their own high-technology development zones through the Torch program, discussed on page 35.[215] Today, there are 56 National Economic and Technological Development Zones spread throughout the country.[216] Enterprises in the zones often receive free or discounted land, R&D support, tax reductions, and refunds on value-added taxes for exports.[217] Some of the zones may be successful, but studies have also found that they often fail to nurture the inter-firm links necessary for innovation, and that companies continue to depend on government support because of the weakness of private finance.[218]

Chinese authorities have renewed their focus on National High-Tech Zones to promote China's innovation capacity and to serve as a base for enterprises "going out" to compete internationally. As outlined jointly by MOST, NDRC and the Ministry of Land and Natural Resources in 2008, the government must promote an environment that nurtures local high-tech enterprises, allowing them to "truly become the main research and development inputs." The government specifically encourages the bureaucracy and the local governments with oversight over the Zones to establish productivity promotion centers; encourage local research institutes and universities to support innovation in high-tech enterprises, including through joint research institutions; promote technology alliances among small and medium-sized enterprises; provide loans; support and protect

[215] Yun-chung Chen, "Limits of Brain Circulation: Chinese Returnees and Technological Development in Beijing," Center on China's Transnational Relation, Working Paper No. 15, pp. 7-8. http://www.cctr.ust.hk/materials/working_papers/WorkingPaper15.pdf
[216] Ministry of Commerce, PRC. http://english.mofcom.gov.cn/chinainvest/cdz.html
[217] U.S.-China Economic and Security Review Commission, *2009 Report to Congress*, November 2009, p. 58.
[218] Yun-chung Chen, "Limits of Brain Circulation: Chinese Returnees and Technological Development in Beijing," Center on China's Transnational Relation, Working Paper No. 15. http://www.cctr.ust.hk/materials/working_papers/WorkingPaper15.pdf

intellectual property; introduce innovations in the use of procurement policy; and encourage stock market listings and new mechanisms to attract private capital.[219]

Government Procurement

The Chinese government uses its procurement policies to nurture domestic technology firms by providing markets for their products. Every year, the Chinese state makes 700 billion RMB in procurement purchases, and according to China's *21st Century Business Herald*, the government is exploring the possibility of raising the procurement budget to purchase technology products that will allow it to subsidize developing industries.[220] In 2009, MOST, the NDRC and MOF threatened in its "Circular on Carrying Out Work On Accreditation of National Indigenous Innovation Products," (Circular 618) to procure products from catalogues that would exclude foreign brands. The government backed down from its more protectionist stances in Circular 618 in the spring of 2010, but across China, local governments still use procurement policies to nurture the nation's own technology companies. It remains unclear the extent to which China will give foreign firms true access to the government purchasing market in the future.[221]

National Standards

China has identified standardization capabilities as an important measure of innovation, and has devoted administrative resources and research funding to support standards projects. The MLP also closely links China's innovation goals with the creation of technical standards incorporating Chinese-developed intellectual property. These efforts have been particularly visible in the telecommunications industry. While the MLP was being readied for release, MIIT formally announced a national standard for 3G mobile telecommunications—TD-SCDMA—to compete against European and American standards. Recognized as an international standard by the International Telecommunications Union (ITU) and further developed in cooperation with the German firm Siemens, TD-SCDMA was rolled out in 2009 and assigned to China Mobile, the PRC's largest carrier and the largest worldwide in terms of subscribers, with the WCDMA standard assigned to China Unicom and the CDMA-2000 standard to China Telecom.

There is considerable debate about the wisdom of industrial policy vis-à-vis TD-SCDMA. The standard's defenders argue that given the size of the Chinese telecom market—the world's largest—China had to have its own. They note that the technical benefits and experience from the project put China in good position to shape 4G

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[219] The State Council General Office, "cujin guoajia gaoxin jishu chanye kaifaqu jinyibu fazhan zengqiang zizhuchuangxin nengli de ruogan yijian (certain views on encouraging the continued development of High-tech Industrial Development Zones to increase indigenous innovation capacity)," February 5, 2008. http://www.gov.cn/ztzl/kjfzgh/content_883810.htm
[220] *21st Century Business Herald*, Xinxing zhanlue chanye guihua 9 yuedi chu cao'an (newly emerging strategic industry plan to release initial draft at the end of September), August 11, 2010.
[221] James McGregor, "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies," US Chamber of Commerce, 2010, p. 16. http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies

technology to its interests. Other observers in China and abroad view TD-SCDMA as a costly failure that delayed the introduction of 3G service in China by several years, and which is now imposing additional costs on China Mobile, as it has had to develop new base stations and handsets for the standard. Thus far, the record of standard-setting based on support for Chinese enterprises has not been very successful. The record is considerably better in cases where China has cooperated actively with international companies, following international norms of standardization.[222]

Intellectual Property

As the number of Chinese innovators grows, PRC officials have recognized that China's aspirations for indigenous innovation are unlikely to be met without a far more credible intellectual property (IP) protection regime that protects the creators of new technologies. The MLP contains targets for the development of products with Chinese IP as well as technical standards based on Chinese IP. The implementation of these proposals has resulted in an incentive structure for Chinese companies, universities, and research institutes to file patents as a measure of success. It is not surprising, therefore, that there has been a steady growth in PRC patenting over the past five years, although the quality of many of these patents has been questioned.

There are also concerns that the implementation of China's industrial policy sometimes puts the intellectual property rights of foreigners at risk.[223] In a 2010 survey of US businesses operating in China by the American Chamber of Commerce in China, 11 percent rated IP enforcement as totally ineffective, 63 percent as ineffective, and only 26 percent as effective or very effective. Enforcement of IPR by foreign companies is increasingly possible in large cities and against large companies, but still rare and difficult in most parts of the country.[224] IP criteria have been built into government procurement and technical standards policies in ways that do not conform to international norms. Chinese "junk patents" have also been used by Chinese technology corporations to win IP settlements against foreign businesses operating in China.[225]

Even if Chinese firms have stolen foreign technology and used it to reverse engineer technologies, technology transfer is more often than not a business decision. Lax enforcement of IPR for foreign companies can deter these companies from providing their technologies to Chinese research and business partners. In many industries, though, such

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[222] Scott Kennedy, Richard P. Suttmeier, Jun Su, "Standards, Stakeholders, and Innovation: China's Evolving Role in the Global Knowledge Economy," *NBR Special Report* # 15 (National Bureau of Asian research, September 2008).
[223] Richard P. Suttmeier, Statement to the Congressional-Executive Commission on China, Washington DC, September 22, 2010. http://www.cecc.gov/pages/hearings/2010/20100922/suttmeierStatement.pdf
[224] Christian Murck, Statement to the Congressional-Executive Commission on China, Washington DC September 22, 2010.
http://www.cecc.gov/pages/hearings/2010/20100922/murckStatement.pdf?PHPSESSID=1ab82c66878f6da6f60d6a88a295de18
[225] James McGregor, "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies," US Chamber of Commerce, 2010, p. 28. http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies

as clean energy, the Chinese market is so attractive to foreign companies that some degree of technology transfer is seen as unavoidable and an acceptable cost of doing business.

Doubts about Industrial Policies for Innovation

In spite of the government's confidence in its industrial policies, China is facing unintended consequences from its initiatives, many of which have been harmful to innovation. The implementation of government-supported innovation is not as coherent as a 'China Inc.' image may lead some to believe, nor are the goals of China's industrial policymakers always aligned with the innovation goals of some scientific planners.[226] Although the innovation planners at MOST have injected their ministry into the enterprise sector, MOST's goals are not always the same as those of the industrial ministries or local governments. The State Council, SASAC, NDRC and powerful governments of technologically advances localities—such as Jiangsu, Shanghai and Beijing—control various companies in high-tech areas. Each of these organizations seeks to promote its companies for its own prestige and benefit. MIIT policies are designed to enhance its guiding role over information technology industries.

As a result, many local governments and industrial bureaucracies favor protecting the interests of particular corporations over enhancing the innovation system—or attempt to select winning industries based on bureaucratic preferences and limited information. Problematic practices include the following:

- SOEs benefit from government backing that privileges them over their private, and usually more innovative, competition. For example, state-owned companies won 70 percent of the bids for government solar energy projects in 2010. It was reported that they underbid their competition because they did not have to be concerned that their investments would not likely pay off for nearly two decades.[227] Likewise, for offshore wind energy projects, SOEs put in winning bids that experts say ignored the risks and costs involved in order to get a foothold in the sector.[228]

- Government agencies like SASAC and the NDRC, as well as local governments like Shanghai and Beijing, have been eager consolidators of state companies under their control. This approach seems attractive for building the economies of scale

[226] Richard P. Suttmeier, "Will China Protect Intellectual Property? New Developments in Counterfeiting, Piracy, and Forced Technology Transfer," testimony before the Congressional-Executive Commission on China hearing, September 22, 2010. http://www.cecc.gov/pages/hearings/2010/20100922/suttmeierStatement.pdf?PHPSESSID=d639b801f86e1aa6acadc22ae48b4da0

[227] Lou Schwartz, "Chinese Firms Developing Solar Power Plants for Less Than 1 Yuan per kWh?" RenewableEnergyWorld.com, September 20, 2010. http://www.renewableenergyworld.com/rea/news/article/2010/09/chinese-firms-developing-solar-power-plants-for-less-than-1-yuan-per-kwh?cmpid=rss

[228] Pu Jun, "High Bids Garnered for Offshore Wind Power Projects," *Caixin Online*, October 12, 2010. http://english.caing.com/2010-10-12/100187828.html

necessary to conduct R&D and deploy products, but it also means elbowing potentially more innovative non-state firms out of the market.

- SOEs and industrial conglomerates in the defense sector have stifled innovation by protecting their interests and preventing other companies from gaining the regulatory approval to build more advanced technology products. For example, Chinese researchers have accused China National Nuclear Corporation of preventing other companies from offering more advanced nuclear reactor designs to Chinese utilities.[229]

- Local governments are tempted to support companies that bring jobs and prestige to their area, and they often lack the long-term vision of the central government. These tensions play out in the megaprojects, in which MOST has criticized local governments for not providing adequate investment in some centrally-sponsored innovation projects with longer time-frames.[230]

- Many state owned enterprises favored by the government have become quite profitable and have contributed to economic growth, but have not necessarily taken the challenges of innovation seriously. Between 2002 and 2007, for instance, the number of research scientists and engineers in SOEs declined slightly, while those in the non-state sector increased markedly.[231] During the same period, R&D spending by enterprises outside of the state sector, such as by Huawei and ZTE, increased considerably more rapidly than that by SOEs. The non-state sector outpaced state-owned companies in the establishment of R&D laboratories and applications for patents within firms as well.[232] This suggests that the profitable position of the state owned enterprises, and their ready access to foreign technology, reduces their incentives to engage in innovative activities.

These problems in China's techno-industrial policies may actually grow more acute as an increasing number of companies outside of the state sector have now come to enjoy government policy privileges that were thought to be mainly the province of the SOEs.

The 2010 *Decision to Accelerate the Development of Strategic Emerging Industries* raises the specter that a significant amount of government funds will be seriously misallocated. Chinese experts have already questioned whether the seven targeted industries can handle a sudden influx of cash.[233] Nor is it clear if China's bureaucracy can manage an even larger set of initiatives given the already substantial strains on it. In addition, despite claims that China can compete in "emerging industries" where foreign

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[229] See the nuclear power case study.
[230] MOST Megaprojects Office, "Guojia keji Da Zhuanxiang Gongzuo Jianbao (Work report on the National Megaprojects, Vol. 3 (Overall Vol. 91), January 20, 2010. http://www.nmp.gov.cn/gzjb/201004/t20100407_1247.htm
[231] National Bureau of Statistics, S&T statistical yearbooks, 2003-2008.
[232] National Bureau of Statistics, S&T statistical yearbooks, 2003-2008.
[233] Benjamin Kang Lim and Simon Rabinovitch, "China mulls $1.5 trillion strategic industries boost: sources," *Reuters*, December 3, 2010. http://www.reuters.com/article/idUSTRE6B16U920101203?pageNumber=2

companies do not have insuperable technological leads, a survey by the *China Securities Journal* found that the markets in many of these industries are currently occupied by multinational corporations, with domestic companies at a distinct disadvantage because of low technology levels. In the carbon fiber and lithium hexafluorophosphate industries, for example, Chinese experts said that many companies, including SOEs, are tapping into government support to invest in these products whether or not they possess the requisite technologies to succeed. According to experts, many of these firms face troubled outlooks as they attempt to go up against foreign firms.[234]

Renewable energy projects, which have been the priority of China's industrial policies over the last few years, and which official media say are slated to receive investments of 5 trillion RMB over the next decade, are already experiencing overinvestment and overcapacity, according to experts and some quarters of the Chinese government.[235] The NDRC warned of overcapacity in the wind-power industry, raising doubts about the government's substantial investments.[236] Chinese experts have pointed out that with central government policy support, local authorities have been building new energy facilities with low efficiency, and that the lack of domestic innovation in the new energy sector has resulted in China's reliance on imported technology and standards.[237] The multi-month delay in the rollout of the Strategic Emerging Industries Decision was the result of wrangling over the clean energy component, in which massive vested interests were at stake.[238]

As in other countries, industrial policy can lead to widespread corrupt practices. For instance, in 2008, MOST, the Ministry of Finance, and the State Administration of Taxation introduced the High-Tech Enterprise Certification Management Policy, which provided for the designation of firms as high-tech enterprises that would then be eligible for generous tax reductions and other policy privileges. A recent investigation revealed widespread fraud in the certification process, with more than 70 percent of the 20,000 enterprises that had received certification having done so under questionable circumstances. An investigation involving a sample of 116 enterprises revealed that 73 percent of them failed to meet the official standards for certification in spite of having received 3.63 billion RMB in tax breaks.[239]

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[234] SOEs like China National Petroleum Corporation, China Petroleum and Chemical Corporation, China National Chemical Corporation and Sinosteel Corporation have tapped into government funds to make major investments in strategic emerging industries. As reported by *People's Daily*, "Multinationals dominate China's strategic emerging industries" via China Business News, November 24 2010. http://cnbusinessnews.com/multinationals-dominate-chinas-strategic-emerging-industries/

[235] Yan Jiangning, "Analysts Warn of Aimless New Energy Investment," *Caixin*, November 6, 2010. http://english.caing.com/2010-11-06/100196229.html

[236] Benjamin Kang Lim and Simon Rabinovitch, "China mulls $1.5 trillion strategic industries boost: sources," *Reuters*, December 3, 2010 http://www.reuters.com/article/idUSTRE6B16U920101203?pageNumber=2

[237] Yan Jiangning, "Analysts Warn of Aimless New Energy Investment," *Caixin*, November 6, 2010. http://english.caing.com/2010-11-06/100196229.html

[238] Author's personal correspondence with Barry Naughton, December 2010.

[239] Zhou Qiong and Yang Aili. "Fabricated High-tech Boom," *Caijing Online*, August 10, 2010. http://english.caing.com/2010-08-10/100168670.html

While many aspects of China's industrial and technology policies have strengthened Chinese industrial capabilities and market power, the picture is at best mixed in terms of innovation. This is becoming evident to a number of policy elites in China, who are struggling to find the right role for the state in enterprise activities. As the product category regulations for government procurement illustrate, the Chinese state is capable of policies that are, in the words of Charles Lindblom, "all thumbs, no fingers," sometimes working against best practices for innovation.[240]

[240] Charles Lindblom, *Politics and Markets: The World's Political-Economic Systems* (Basic: New York, 1977).

The International Dimension of Chinese Scientific and Technological Development

The second cardinal choice in China's emerging model of science—after the choice between planning and the market—is that between stressing foreign technology or domestic sources of innovation. China's scientific development has benefited enormously from involvement in the global trading system and in transnational scientific networks. Since Deng Xiaoping's "reform and opening" policies began in 1978, knowledge and technology have flowed into China from various channels: from companies that absorb and re-innovate foreign technologies and processes; from scientific and high-tech development programs with foreign corporations, universities and foreign governments; from returned Chinese expatriates (returnees) who have transferred skills and knowledge gained from studies and employment abroad; as well as from corporate theft and espionage.

China's participation in global economic and scientific activities contributes to knowledge, technologies and products from which all, in theory, benefit. But as one scholar of the subject has noted, "the win-win, positive sum assumptions about cooperation in science have become complicated by the fact that the development of commercial and national security applications of new knowledge often introduce competitive pressures and the possibility of zero sum outcomes."[241]

China's call for "indigenous innovation" in the MLP reflects both its modern aspirations in science and technology and an ambivalent relationship towards foreign technology. In the 19th century, foreign pressures on China from a technologically superior West were characterized by a deep and painful cultural introspection which identified scientific and technological underdevelopment as a critical component of China's weakness. At times, foreign science and technology has been seen largely in instrumental terms of serving Chinese cultural values and institutions.

The question that many foreign observers are now asking is whether China, which has positioned itself so well to reap the benefits of "techno-globalism," has begun to undermine the system of mutual gain through "techno-nationalist" policies that enhance its own commercial and military capabilities at the expense of others. An examination of the many linkages China maintains with the international environment illustrates a complex pattern of mutual benefits for China and the United States, uneven gains, and possibilities for "beggar thy neighbor" outcomes.

Indigenous Innovation

China's policymakers first proposed the notion that China would seek to enhance its "indigenous innovation" capacity as the foremost goal of its science policy during

[241] Richard P. Suttmeier, "From Cold War Science Diplomacy to Partnering in a Networked World: 30 Years of Sino-US Relations in Science and Technology," p. 10. www.hmc.edu/files/hixonforum/2009/suttmeier.doc.

planning meetings for the MLP in 2003, a signal of China's growing confidence in its technological capabilities.[242] By February 2004, Premier Wen Jiabao had publically weighed in on the issue, telling Chinese scientists that "we are a developing great nation; we must positively study and import (*yinjin*) foreign advanced technology. At the same time, the basis of scientific advancement must be placed on the ability to increase our indigenous innovation capability."[243] The decision to promote the expression "indigenous innovation" was controversial. During 2003 MLP planning sessions, certain experts and government departments (including MOST) objected to the phrase, fearing it had a ring of "sealed off" innovation, potentially overturning a longstanding tenet of welcoming foreigners who wished to contribute to China's economic and technological development. A MOST representative proposed that China instead use the term "open innovation," and even after losing the debate, MOST and other departments continued to use the phrase "indigenous innovation under open conditions."[244]

While "indigenous" innovation captures part of the meaning of *zizhu chuangxin* for English speakers, so might "independent," "homegrown," "self-initiated," "original" or "sovereign" innovation. To Chinese officials, "indigenous innovation" can represent a long-term aspiration to exercise sovereign control over the core scientific and technological capacities that are the root of a nation's economy. It can also represent a techno-nationalist approach to scientific and technological development in which contacts with outsiders are viewed instrumentally. According to a commentary on President Hu Jintao's "theory of indigenous innovation" from the CCP's *Guangming Daily*, the pursuit of technology is intended to serve China's exclusive interests. China, it states, "must possess indigenous technological innovation capacity in order to possess the initiative in international competition."[245]

A number of foreign observers have pointed out that "indigenous innovation" policies have restricted market access for foreign companies in order to spur China's domestic technology development. Such efforts, including in intellectual property, procurement, standards and joint venture policies (described in the previous section) are

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[242] *Science Times*, "zizhu chuangxin shi guoce: fang kexue jishu bu zhengce fagui si sizhang Mei Yonghong" (Indigenous Innovation is National Policy: Interview with MOST Policy and Regulation Office Director Mei Yonghong) September 16, 2010. http://www.stdaily.com/kjrb/content/2010-09/16/content_230413.htm

[243] *Science Times*, "Xu Guanghua: Zai Keji Bu Dangfeng LianZheng Jianshe he Fan Fubai Huiyi Shang de Jianghua" (Xu Guanghua: Speech at the Ministry of Science and Technology's Party Work Style Upright Management Construction and Anti-Corruption Meeting), March 18, 2004. http://scitech.people.com.cn/GB/126054/140641/140643/8486233.html

[244] *Science Times*, "zizhu chuangxin shi guoce: fang kexue jishu bu zhengce fagui si sizhang Mei Yonghong" (Indigenous Innovation is National Policy: Interview with MOST Policy and Regulation Office Director Mei Yonghong) September 16, 2010. http://www.stdaily.com/kjrb/content/2010-09/16/content_230413.htm; MOST, "pinglun: zizhuchuangxin shi kaifang tiaojian xia de chuangxin (assessment: indigenous innovation is innovation under open conditions," *Science Times*, January, 8, 2006. http://www.most.gov.cn/ztzl/jqzzcx/zzcxmtbd/200601/t20060119_28061.htm

[245] *Guangming Ribao*, Jianshe chuangxin xing guojia guanjian zai zizhuchuangxin (Building an Innovative-Type Nation: The Key is Indigenous Innovation), People's Theory Web, Jan. 11 2006. http://theory.people.com.cn/GB/49150/49152/4017322.html

often pursued by China's industrial bureaucracies, like SASAC and MIIT, with the goals of short-term technology capture rather than innovation.

But rather than becoming a full-blown policy to restrict market access, which could badly harm China's long-term competitiveness, "indigenous innovation" measures have actually encouraged various types of foreign interaction. Chinese leaders have counseled that pragmatism and cooperation with foreign entities continues to be an integral part of achieving China's desired economic and scientific transformation.[246] "Indigenous innovation," Hu Jintao said, is about "increasing the nation's innovation capacity [by] accumulating original (*yuanshixing*) innovations, [but also accumulating] integrated innovation and innovation from importing, digesting, absorbing and re-innovating."[247] In short, China continues to view its participation in global innovation and commercial networks as crucial to the nation's scientific development. The bottom line of "indigenous innovation" policies is not technological autarky, but a laser focus on shaping foreign interactions to serve national innovation goals.

Commercial Linkages: Foreign Multinationals and Technology Transfer

S&T cooperation through commercial channels began in the early 1980s with foreign firms transferring technology to China through equipment sales and licensing agreements. As China's foreign investment regime liberalized during the course of the 1980s, technology transfer increasingly became linked to foreign investment projects in which multinational corporations seeking to expand into China entered into joint ventures. By the 1990s, China had developed increasingly sophisticated foreign investment regulations intended to extract as much technology as possible from foreign investors under its so-called "market for technology" strategy. Although US firms were not alone in transferring technology to China, in terms of scale and value of investments, levels of technology, and styles of technological management, US companies have been a leading source of foreign technology for China since the early 1980s.

On one level, the value of foreign technology for Chinese economic transformation is indisputable. China has used foreign technology—broadly understood to include hardware, know-how, and technology management—to transform its industrial economy. Among China's technology users (electricity suppliers, manufacturers etc.), there has been a strong bias in favor of foreign technology and a distrust of Chinese technology suppliers. Chinese users of foreign technology were often content merely to deploy it and profit from it, in marked contrast to practice in Japan and Korea where for every yen or won spent on

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[246] *Xinhua*, "Hu Jintao zai quanguo kexue jishu dahui shang de jianghua" (Hu Jintao's Speech at the National Science and Technology Congress) January 9 2006. http://news.xinhuanet.com/st/2006-01/09/content_4030855_1.htm

[247] *Guangming Ribao*, "Jianshe chuangxin xing guojia guanjian zai zizhuchuangxin. Xuexi Hu Jintao tongzhi zai quanguo keji dahui shang de jianghua xilie pinglun zhi er" (Building an Innovative-Type Nation: The Key is Indigenous Innovation. Second Series Assessment Studying Comrade Hu Jintao's Speech at the National Science and Technology Congress), Jan. 11 2006. http://theory.people.com.cn/GB/49150/49152/4017322.html

procuring technology, several times that amount would be spent on assimilating it.[248] China's stance has seemingly now begun to change, with the state promoting a far more coordinated and organized technology assimilation program. In a number of the national megaprojects, such as the large aircraft and nuclear energy projects, special organizations and large teams have been established to master the knowledge and technology that is being supplied from abroad.[249]

As described in the previous section, the Chinese government controls many enterprises and has strong regulatory capabilities, allowing it to influence the terms on which foreign nationals do business in China. For the chance to compete in China's huge market, multinationals have at times been willing to part with their intellectual property through joint ventures. This situation is readily apparent in the area of high-speed rail. China's Ministry of Railways (MOR) initially hoped to build a home-grown high-speed rail system using China's own intellectual property. But in 2004, the Ministry announced that the nation's technologies were "immature" and called on Chinese companies to digest foreign technology instead. In exchange for access to China's high-speed rail market, foreign corporations would have to abide by industry-wide "local content" requirements, which according to official statements, meant that that at least 70 percent of rail equipment had to come from Chinese companies. [250]

In but one example of the results of this program, in 2005 the China National Railroad Corporation (CNR) invited the German firm Siemens to join them on a bid to supply passenger trains for the Beijing-Tianjin high speed railway. The consortium was awarded an initial contract to supply 60 passenger trains worth $919 million. To satisfy content requirements, the first three of the advanced trains were built in Siemens' German plant, and the remaining 57 were built in China at a CNR plant in Tangshan after Siemens trained 1,000 CNR technicians to manufacture the advanced equipment.[251]

By partnering with CNR, Siemens hoped to gain business in a country that plans to spend $730 billion on railroads and $150 billion on subway systems in the next five years.[252] Nor was it alone in making that choice, as France's Alstom, Japan's Kawasaki Heavy Industries and Canada's Bombardier also entered into partnerships with state-controlled Chinese companies.[253]

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[248] For Korea's experiences with technology assimilation, see The World Bank. *Korea as a Knowledge Economy: Evolutionary Processes and Lessons Learned,* (The World Bank, Washington DC, 2006). http://info.worldbank.org/etools/docs/library/235384/KoreaKE-Overview.pdf.
[249] Author interviews, Beijing, 2010.
[250] Jamil Anderlini, "China: A Future on Track," *Financial Times*, September, 22, 2010. http://www.ft.com/cms/s/0/2b843e4c-c745-11df-aeb1-00144feab49a.html
[251] James McGregor. "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies."US Chamber of Commerce, 2010. http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies
[252] James McGregor, "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies," US Chamber of Commerce, 2010, p. 32. http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies
[253] Norihiko Shirouza, "Train Makers Rail Against China's High-Speed Designs," The Wall Street Journal, November 17, 2010. http://online.wsj.com/article/SB10001424052748704814204575507353221141616.html

The Beijing-Tianjin high speed railway opened to great fanfare before the 2008 Olympics, and by March 2009, Siemens had announced a follow-on project to supply 100 trains for a Beijing-Shanghai high speed railway. To its surprise, however, the Ministry of Railways denied the existence of the deal, saying China would use it own "indigenous technology." Instead, MOR awarded CNR a $5.7 billion contract for the trains, with Siemens contracted to supply certain vital components for $1 billion.

The result of Siemens' decision to transfer technology to CNR was the loss of its technological advantage to what could soon become a global competitor.[254] Indeed, CNR reports that it will boost the share of revenue from exports from 10 percent today to 50 percent by 2015. Foreign interest in Chinese rail technology is growing, even in the United States, where California has encouraged Chinese bids on a planned high-speed rail project.[255]

As noted above, China's entry into the WTO was supposed to preclude it from demanding technology from foreign companies in exchange for access to its domestic market. Recent reports, however, reveal that these practices have continued. According to a September 2010 *Wall Street Journal* article, for instance, MIIT is preparing a ten-year plan to make China "the world's leader" in developing battery-powered cars. American car executives familiar with a draft of the plan have argued that the plan would compel foreign auto makers that want to produce electric vehicles in China to take a minority stake with a Chinese joint venture partner. In doing so, the foreign automaker would have to share its critical technologies.[256] Once again, China has produced a policy proposal tinged with techno-nationalist elements, which is likely to elicit a strong response from affected foreign and Chinese parties. Whether push-back will lead to a modification of the proposal, as has occurred in other cases, remains to be seen.[257]

As has been suggested in this discussion, governments and corporations in both the United States and China have had to make difficult choices about whether and how to work with each other, based on the perceived costs and benefits of these interactions.

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[254] James McGregor. "China's Drive for 'Indigenous Innovation:' A Web of Industrial Policies," US Chamber of Commerce, 2010, 32-33. http://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies.
[255] "Under China's Competitive Radar," *The Wall Street Journal,* September 27, 2010, C10; *2.6billion.com*, "Schwarzenegger wants China to invest in California's High-Speed Rail Network," September 14, 2010. http://www.2point6billion.com/news/2010/09/14/schwarzenegger-wants-china-to-invest-in-californias-high-speed-rail-network-7094.html
[256] Norihiko Shirouzu, "China Spooks Auto Makers: Foreign Companies Fear New Rules on Electric Cars Will Erode Intellectual Property," The Wall Street Journal, September 16, 2010. http://online.wsj.com/article/SB10001424052748704394704575495480368918268.html
[257] For example, in 2004 China backed off earlier attempts to apply preferential value-added tax rebate rules to domestic over foreign-sourced semiconductors. See Gary Clyde Hufbauer and Jared C. Woollacott, "Trade Disputes Between China and the United States: Growing Pains so Far, Worse Ahead?," Working Paper 10-17, Peterson Institute for International Economics, December 2010. http://www.iie.com/publications/interstitial.cfm?ResearchID=1722
Scott Kennedy, "Not As Scary As It Sounds," *China Economic Quarterly*, September, 2010;

China, for its part, has not always viewed international cooperation as being decisively to its advantage, and has at times embraced collaboration, and at other time autonomy, in its technological development. In China, the case of nuclear power is illustrative of the tensions entailed in these decisions.

Case Study III - Nuclear Power: Innovation in State Enterprises and the Conundrum of Foreign Technology

China's program in nuclear energy demonstrates how China has wrestled with uncertainty about whether to "go it alone" to advance indigenous technology or to utilize foreign technology to serve its development needs. From the beginning, debates over the relative weight to be given to indigenously-developed technology versus imported foreign technology have characterized China's nuclear expansion plans. Each choice had its own logic and supporters in China's government and technical communities. In the development of civilian nuclear technology, the PRC chose a two-pronged approach: to actively adopt and improve third-generation reactor technology acquired through foreign multinational corporations, but also to invest in indigenous fourth-generation reactors it hopes will leapfrog the technologies of the most advanced nuclear nations.[258] While it is tempting to view this as China's national vision for linking foreign technology adaptation with domestic innovation goals, this decision was very much bureaucratically-driven. China's decisions about nuclear technology transfer have come from contentious political bargaining among interest groups—including scientists, state nuclear conglomerates, state power companies and organs of the State Council.

China plays an important global role in nuclear energy's technological development due, in part, to the growth potential of its market. China's expansion and modernization plans in civilian nuclear energy are the most aggressive in the world. China currently operates 12 nuclear power reactors, is constructing 24 others, and has plans for dozens more in coming decades.[259] The Chinese government announced its ambitions to expand the nuclear energy sector in a 2002 draft plan that called for China to derive between 10 and 30 percent of its electricity from nuclear power by 2050.[260] This also heralded the start of a program for rapid scientific advancement in nuclear energy,[261] and to the current goal of raising the amount of electricity derived from nuclear power from 8

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[258] Second generation nuclear reactors are those now largely in operation throughout the world; third generation reactors, introduced in Japan in the 1990s and now being built in China by foreign multinationals, have incremental advances on second-generation designs that make them cheaper and safer; fourth generation reactors are those currently in the concept stage. World Nuclear Association, "Advanced Nuclear Power Reactors." http://www.world-nuclear.org/info/inf08.html
[259] World Nuclear Association, "Nuclear Power in China," updated September 2010. http://www.world-nuclear.org/info/inf63.html
[260] Xu Yi-chong, "Nuclear Energy in China: Contested Regimes," Energy 33 (August 2008).
[261] Nicobar Group, "Nicobar Introduction to the Chinese Nuclear Industry." http://www.nicobargroup.com

Gigawatts of electricity (GWe) today to 400 GWe, by 2050.[262] One of the sixteen National Megaprojects of the MLP calls for China to develop and deploy "large-scale nuclear power plants with advanced pressurized water reactors and high-temperature gas cooled reactors."[263] The NDRC's 2007 Nuclear Power Mid- to Long-Term Development Plan later proposed investment of 450 billion RMB ($67 billion) in nuclear energy from 2005 to 2020.[264]

State-centered Innovation: Government conglomerates and the R&D system.

State conglomerates and research institutes dominate China's scientific efforts in nuclear energy in large part due to the origins of nuclear R&D in national defense. China's most important nuclear technology player is the China National Nuclear Corporation (CNNC), a defense industry conglomerate that answers directly to the State Council. CNNC was established in 1988 to direct both civilian and military nuclear activities at all levels of the nuclear fuel cycle. It operates over 100 subsidiary enterprises and institutions and is responsible for managing the majority of China's nuclear power plants, conducting R&D, and adapting foreign technology for China's nuclear expansion. The China Institute of Atomic Energy (CIAE) is CNNC's R&D arm[265] and China Nuclear Power Engineering Corporation (CNPEC) is its engineering and construction arm.[266] CNNC claims that one quarter of its employees are engaged in R&D activities.[267] The China Nuclear Engineering Construction Corporation (CNECC) is a defense enterprise with responsibilities in nuclear engineering projects and R&D.[268] The China Guangdong Nuclear Power Group (CGNPG), broken off of CNNC to offer competition in the nuclear energy sector in 1994, operates four reactors in southern China, using designs from the French nuclear company Areva.[269]

Various schools and research institutes engage in basic and applied nuclear power research, often funded by CNNC and national S&T programs. Tsinghua University's Institute of Nuclear and New Energy Technology (INET) is a leader in the development of fourth generation reactor technology. Eight institutes recently received financial support from the 973 Program to conduct basic research in nuclear energy: Shanghai Jiaotong University, Tsinghua University, the Beijing University of Science and Technology, North China Electric Power University, the Nuclear Power Institute of China, CIAE, the

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[262] World Nuclear Association, "Nuclear Power in China," updated September 2010. http://www.world-nuclear.org/info/inf63.html
[263] Ministry of Science and Technology, *Zhongguo kexue jishu fazhan baogao 2008* (China Science and Technology Development Report 2008, Kexue jishu wenxian chubanshe, 2009, 56
[264] NDRC, *hedian zhonqi fazhan guihua 2005-2020* (Nuclear Power Mid to Long Term Development Plan 2005-2020) October 2007. http://www.sdpc.gov.cn/nyjt/nyzywx/W020071102337736707723.pdf
[265] NTI, "China Institute of Atomic Energy." http://www.nti.org/db/china/ciae.htm
[266] China National Nuclear Corporation, "China Nuclear Power Engineering Corporation has been licensed," June 20, 2006. http://www.cnnc.com.cn/2006-06-20/000226292.html
[267] Xu Yi-chong, "Nuclear Energy in China: Contested Regimes," Energy 33 (August 2008), 1200-1201.
[268] China Nuclear Engineering Group Co., "Company Introduction." http://www.cnecc.com/zi_jt_jianjie.asp
[269] *CGNPG, http://www.cgnpc.com.cn/n1093/n463576/n463613/index.html; Mark Hibbs, "China Should Remain Prudent in its Nuclear Fuel Path," Nuclear Energy Brief, November 22, 2010. http://carnegieendowment.org/publications/index.cfm?fa=view&id=41969#*

Shanghai Nuclear Engineering Research & Design Institute (SNERDI), and the China Nuclear Power Technology Research Institute (CNPRI).[270]

In the nuclear sector, China's state-led scientific funding apparatus appears capable of directing funding to long-term high-risk/high-payoff fourth-generation projects. Starting in the 1980s, the 863 Program has played a critical role in funding the development of advanced fast reactor and high-temperature reactor technologies.[271] China now has about 15 civilian experimental reactors. The China Advanced Research Reactor is currently under construction and the China Experimental Fast Reactor (CEFR) reached criticality in July 2010,[272] making China the 8th nation to prove the technology.[273]

The most intriguing of China's experimental reactors, however, have been its fourth-generation high-temperature gas-cooled "pebble bed" modular reactors. Powered by graphite spheres containing fissile material rather than rods, these reactors are designed to produce 30 percent more energy for a given amount of fuel and to have no risk of overheating.[274] Pebble bed reactors produce heat that can be extracted and used to deliver process heat to the coal and petrochemical industries, saving oil and gas and reducing greenhouse gas emissions. The HTR-10 developed by Tsinghua University's INET and long supported by the 863 Program reached criticality in 2003. The construction of the 210MWe HTR-PM, scheduled for completion around 2013, is intended to prove the commercial viability of the pebble bed modular reactor technology, and the no-risk potential of surpassing design-limit temperatures, obviating the need for emergency cooling and shutdown systems.[275]

South Africa has tried to develop a commercially-viable pebble bed reactor, so far without success. The US is considering a pebble bed reactor as one of three options for its Next Generation Nuclear Plant, although this program is not expected to begin until 2018. Scientists predict that if the PRC program to make a commercially-viable pebble bed reactor is successful, it will represent a revolution in reactor technology—perhaps the largest advance in a quarter of a century.[276]

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[270] 973 Program website. http://www.973.gov.cn/

[271] *Zhongguo Gongye Bao*, "Shiyan Kuaidui Dadao Linjie: Zhongguo Heidan Huo Po Nengyuan Pingjing" (China Experimental Fast Reactor reaches Criticality) July 7, 2010. http://www.cinn.com/zbzz/211285.shtml.

[272] World Nuclear Association, "China's Nuclear Fuel Cycle," updated August 2010, p. 5. http://world-nuclear.org/info/inf63b_china_nuclearfuelcycle.html; Li Xinmin, "Zhongguo Si dai Hedian Zizhu Chuangxin Xin Da Tupo: Shiyan Kuaidui Shouci Linjie" (China's Fourth Generation Nuclear Power Indigenous Innovation Breakthrough: Experimental Reactor Reaches Criticality) CCnews, August 2, 2010, http://ccnews.people.com.cn/GB/12313703.html.

[273] *Zhongguo Touzi*, August 2010, p. 114

[274] Phil McKenna, "Is the US Lagging on Nuclear Power Technology?" *New Scientist*, Vol. 25, Issue 2750 (March 6, 2010), p. 9.

[275] Next Big Future, "Current Status and Technical Description of Chinese 210MWe HTR-PM," Weblog entry, February 12, 2010. http://nextbigfuture.com/2010/02/current-status-and-technical.html

[276] Charles W. Forsberg and David L. Moses, "Safeguards Challenges for Pebble-Bed Reactors Designed by People's Republic of China" (Oak Ridge, Tennessee: Oak Ridge National Laboratory, November 2009), p. ix.

The Foreign Technology Conundrum

Given China's significant early investments in civil nuclear power, by the early 2000s, supporters of indigenous nuclear technology were confident that China would undertake its planned expansion of nuclear energy with minimal outside help. CNNC, promoting its business interests and the views of some in the nuclear science community, called for China's "self reliance," in nuclear technology, "assisted by international cooperation," with the emphasis squarely on "self reliance."[277] China's national leadership also pushed this position, and in 2002, then-Vice President Hu Jintao declared that "the nuclear energy industry is a strategic industry and China needs to develop its own technology for its expansion. No money can buy the core technology. Developing indigenous design and technology is the only way for nuclear expansion."[278]

Yet other institutional players were determined to prevent China from relying exclusively on indigenous technology. Major electricity companies and their backers eager to ensure reliable electricity supplies for the nation were less willing to bet on China's technological capacity. In 2003, the National Development and Reform Commission (NDRC), China's economic planning body, announced that it would open bidding to foreign companies to build four third-generation reactors that would become China's most advanced commercial reactors. When the NDRC drafted the 11th Five Year Plan (2006-2011) in 2005, it eliminated the previous Five Year Plan's emphasis on self reliance, instead calling for adopting the most advanced nuclear technology from foreign suppliers.[279]

Alarmed by this change of direction, the CNNC and members of the state nuclear industry argued that introducing foreign technology would allow foreigners to "control" the nuclear industry. They made a case that China's resources would be better used in support of China's own technological development. China was then developing an indigenous reactor called CNP1000, and the CNNC feared it would be passed over for development funds and commercialization. Many also feared that if multinational companies were to build reactors in China, they would transfer only inferior or outdated technology. In previous deals with France, Russia and Canada, China did not gain ownership of the reactor technology and designs, nor did they manage the construction of the reactors.[280]

Such tensions within the bureaucracy did not reverse the policy shift, but influenced China's high demands from multinational nuclear firms during the bidding process, which culminated in a $5 billion agreement with the then-British-owned American nuclear subsidiary Westinghouse.[281] The US Government was heavily involved

[277] Xu Yi-chong, "Nuclear Energy in China: Contested Regimes," *Energy* 33 (August 2008), 1201-1202.
[278] Xu Yi-chong, "Nuclear Energy in China: Contested Regimes," *Energy* 33 (August 2008), 1201-1202.
[279] The NDRC is the leading economic planning body of the Chinese state, and its decision is thought to have taken account of economic concerns and the desire of the electricity companies to quickly bring on line reliable sources of power.
[280] Xu Yi-chong, "Nuclear Energy in China: Contested Regimes," Energy 33 (August 2008), 1201-1203.
[281] The United States has been interested in cooperating with China in the realm of nuclear energy since the late 1980s, but non-proliferation concerns frustrated the conclusion of a government to government

in promoting Westinghouse's bid, not only from a commercial advocacy standpoint but also due to significant US Government R&D investment is developing the Westinghouse technology. To secure the deal, Westinghouse agreed to a full transfer of technology (according to the US Secretary of Energy, the Chinese government was "very demanding" on this point), and the United States also accepted China's membership in the Generation IV International Forum, which carries out R&D for the next generation of nuclear reactors.[282]

Westinghouse had not begun a single new reactor project since 1996, so much was at stake for it as it went up against French and Russian competitors. Its loss would not only be a competitors' gain, but Westinghouse also gambled that China would not be self-sufficient in nuclear reactor design by the time it built the four contracted AP-1000 units. According to some reports, Westinghouse believed it could earn money by consulting on future reactor projects, replenish a nuclear component supply chain that had been broken in the United States, and demonstrate the viability of the AP-1000 reactors to US power utility companies.[283]

China, for its part, was determined to make the most of the Westinghouse agreement for its own technological benefit. To build the reactors, Westinghouse joined a consortium with CNNC,[284] and the State Nuclear Power Technology Corporation (SNPTC), which the Chinese government created in 2007 to manage the technology transfer process of Westinghouse's third-generation nuclear reactor technology. Some reports claim SNPTC has repeatedly clashed with Westinghouse in efforts to speed up the localization of AP-1000 production.[285] SNPTC and Tsinghua University also set up the State Research Center for Nuclear Power Technology to accelerate China's independent development of third-generation nuclear power.[286] In addition, the vast majority of the funding in the

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agreement needed to allow US companies to enter the market. As a result, the US ceded the market to France, followed later by Canada and Russia. The conclusion of the 1998 US-China Peaceful Uses of Nuclear Technology (PUNT) Agreement between the Department of Energy and China's State Development and Planning Commission (predecessor to NDRC) now allows cooperation on nuclear technology and addresses export controls, nuclear emergency management and safety, and waste management, and paved the way for the 2006 deal for the construction of four civilian nuclear power plants in China by Westinghouse.
U.S. Department of Energy, "U.S.-China Energy Cooperation."
http://www.pi.energy.gov/usa_china_energy_cooperation.htm

[282] Xu Yi-chong, "Nuclear Energy in China: Contested Regimes," Energy 33 (August 2008), 1201-1203; US Department of Energy. "U.S.-Chinese Agreement Provides Path to Further Expansion of Nuclear Energy in China." http://www.energy.gov/news/archives/4536.htm; GEN IV International Forum. http://www.gen-4.org/

[283] Nuclear energy consultant based in China, interview with author, August 2010.

[284] Westinghouse, "SNPTC/CNNC, Westinghouse and the Shaw Group Celebrate First Concrete Pour at Sanmen Nuclear Site in China," April 19, 2009.
http://westinghousenuclear.mediaroom.com/index.php?s=43&item=183

[285] Mark Hibbs, "China Should Remain Prudent in its Nuclear Fuel Path," Nuclear Energy Brief, November 22, 2010. http://carnegieendowment.org/publications/index.cfm?fa=view&id=41969#

[286] World Nuclear Association, "China's Nuclear Fuel Cycle," Updated August 2010, p. 5. http://world-nuclear.org/info/inf63b_china_nuclearfuelcycle.html

nuclear energy megaproject has gone to projects to "digest" and "absorb" Westinghouse's technology rather than to fourth-generation reactor R&D.[287]

As specified in its deal, Westinghouse (now owned by Japan's Toshiba) is collaborating with SNPTC to co-develop larger reactor designs than its current AP-1000s. They will have Chinese-owned intellectual property and will be mass produced for the Chinese market. Construction of these late third-generation CAP-1400 reactors, based on the AP-1000, is scheduled to begin in 2013.[288] Westinghouse also faces competition in China, both from Areva's EPR reactor, which the French company offered to build through a deal with CGNPG, and from the China Pressurized Water Reactor, CPR-1000, which China adapted from an earlier Areva design. Rumors have circulated in Beijing that China may back away from a plan to permit Westinghouse to build all of a first group of inland reactors in favor of these "cookie-cutter" CPR-1000s.[289]

Implications of China's rise in nuclear energy technology

In light of these developments, did China's decision to import nuclear technology constitute an effective innovation strategy? China facilitated the transfer of technologies from both American and French companies, and has proven its ability to construct reliable third-generation power plants, albeit with continued outside help. The record is not entirely clear, however. Two professors of management at Tsinghua University allege that the vested interests of the state nuclear conglomerates, particularly CNNC, have stifled nuclear energy technology development. In their view, CNNC has pushed for building its own outdated reactor designs and elbowed the most advanced technologies out of the market. For example, China Huaneng Group, another state power corporation, tried repeatedly to enter the nuclear market and to commercialize Tsinghua's fourth generation pebble bed reactor, but remains unable to break CNNC's opposition to its plans.[290] Thus, CNNC's calls for "indigenous innovation" in the early 2000s may be seen as a measure to protect its outdated technology at the time. After acquiring foreign technology through Westinghouse in the last few years, its opposition to new Chinese technologies could now represent its desire to divert money to its own business, and away from leapfrog innovation efforts in China's nuclear power community.

While China's potential to commercialize fourth generation nuclear reactor technology is difficult to evaluate, and though the PRC still relies on foreign technology in the new reactors it is building, the World Nuclear Association notes that China is rapidly becoming self-sufficient in reactor design and construction, and that future Chinese reactors may be some of the world's most advanced.[291] Even if China's more ambitious projects—such as the pebble bed reactor—fail to achieve breakthroughs, China can rely on

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[287] Ministry of Science and Technology, Zhongguo kexue jishu fazhan baogao 2008 (China Science and Technology Development Report 2008, Kexue jishu wenxian chubanshe, 2009, 56
[288] Xu Yi-chong, "Nuclear Energy in China: Contested Regimes," *Energy* 33 (August 2008);
[289] Mark Hibbs, "China Should Remain Prudent in its Nuclear Fuel Path," Nuclear Energy Brief, November 22, 2010. http://carnegieendowment.org/publications/index.cfm?fa=view&id=41969#
[290] Unpublished private paper provided to author.
[291] World Nuclear Association, "Nuclear Power in China," updated September 2010. http://www.world-nuclear.org/info/inf63.html

economies of scale and expansion opportunities in its home market to refine its technology and learn how to produce the technology cheaply on its own.

China now has a "going out" strategy to sell its technology on international markets. At present, China's only foreign nuclear projects are in Pakistan—where CNNC helped the government construct two nuclear reactors at its Chashma complex in Punjab province, has contracts to build two more, and is now in talks to export a 1000 MWe nuclear power plant—but the coming decade could very well see China aiming to sell competitively-priced nuclear energy to emerging market nations of the Middle East, South America, Africa and Southeast Asia.[292] To really gain traction in global markets, China will have to continue to absorb third-generation reactor technology, and make licensing deals with Westinghouse or Areva to export the technologies that were transferred (transfer agreements are often made only for China's domestic use). In the longer term, advances in pebble bed reactors may provide China with less expensive civilian nuclear technology marketable to a wider range of nations.[293] China's technological advances would therefore not only have the potential to steal market share from foreign companies, but give Western nations less leverage to ensure that nations that import the reactors institute proliferation safeguards.[294]

Some observers also note the potential for China's nuclear expansion plans to set back US energy interests. On the one hand, successful construction and start-up of AP-1000 reactors would give US utilities the confidence to place orders for some of Westinghouse's reactors. On the other hand, nuclear-component forges in Japan, Korea and France have limited global capacity to produce nuclear reactor vessels and steam generators. If there is to be a nuclear energy renaissance in the United States, as some hope, and if the Chinese reactor programs were keep up their momentum, Chinese demand could absorb the global capacity to supply critical reactor components for years to come.[295] The resulting component supply challenges could become a blessing in disguise, however, by incentivizing the US nuclear industry to consider re-commissioning nuclear component forges in the United States.

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[292] Nuclear energy consultant based in China, interview with author, August 2010; Chen Aizhu, "China Company Aims to Build Pakistan Big Nuclear Plant," *Reuters*, September 20, 2010. http://in.reuters.com/article/idINIndia-51605920100920
[293] Idaho National Laboratory, Philip Casey Durst et. al. "Nuclear Safeguards Considerations for the Pebble Bed Modular Reactor (PBMR)" (October 2009)
[294] Charles W. Forsberg and David L. Moses, "Safeguards Challenges for Pebble-Bed Reactors Designed by People's Republic of China" (Oak Ridge, Tennessee: Oak Ridge National Laboratory, November 2009), p. ix. As Secretary of Energy Steven Chu has warned, "if the United states does not have a broad fast reactor research program, we will have no opportunity to influence design of…foreign [designed] reactors from a vital national security perspective such as proliferation resistance." Qtd. Phil McKenna, "Is the US Lagging on Nuclear Power Technology?" *New Scientist*, Vol. 25, Issue 2750 (March 6, 2010), p. 9.
[295] This point was conveyed to the authors by Marco DiCapua, January 2011.

Beyond Technology Transfer: The Rise of Foreign R&D Centers

In addition to some of the drawbacks described in the above case study, technology transferred from foreign firms through purchase and assimilation may not be the desired or most feasible way for China to launch new industries. China's 2001 accession to the WTO required that China no longer demand technology from foreign companies for market access. Many Chinese scientists and planners feel, in any case, that foreign companies cannot be counted on to transfer the technologies sought by China's sophisticated manufacturers or companies competing with foreign firms in the design of new processes and devices. Acquiring foreign technology may be useful in targeted areas in which Chinese industries need to catch up, but not for creating the next round of lucrative discoveries and "leapfrogging" foreign firms. Considering also the steep royalties demanded and the dependency on foreign technology that it cultivates, the appeals of "indigenous innovation" are inescapable.[296]

It is in the context of the limits of technology transfer for its innovation goals that China has sought to encourage new forms of knowledge transfer, most notably through foreign-run R&D centers. In fact, as China began to adjust its own industrial and technology policies in anticipation of WTO membership, foreign companies began to show increasing interest in performing R&D in China.

Foreign investments in R&D grew slowly in the early 1990s, mainly with the initiation of contracts for research and technical services from Chinese universities and research institutes. R&D activities were then added to corporate innovation strategies, especially for firms in information technology, computers, electronics and biotechnology. Since IBM first established a wholly-owned research facility in Beijing in 1995, well-known MNCs such as Intel, Microsoft, Hewlett-Packard, General Electric, Nokia, Ericsson, 3M, Samsung and Panasonic have set up R&D centers in China.[297] US companies note that they are forced to conduct R&D in China in order to produce products tailored to the Chinese market, and in order to exploit pools of science and engineering talent essential for global competition. In surveys of international companies, China now ranks first among all economies when asked where their future R&D centers are likely to be located.[298]

China's Ministry of Commerce says that there are now more than 1,200 foreign MNC R&D centers in China, representing an investment of $12.8 billion.[299] According to the National Science Foundation's (NSF) Science and Engineering Indicators, MNCs spent $804 million in R&D in China in 2006, or 3 percent of all overseas MNC R&D

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[296] Cong Cao, Richard P. Suttmeier, and Denis Fred Simon, "China's 15 Year Science and Technology Plans," *Physics Today,* December, 2006.
[297] Chen Yun-Chung, Jan Vang and Cristina Chaminade, "Regional Innovation Systems and the Global Location of Innovation Activities: Lessons from China," Paper No. 2008/18
http://www.lu.se/upload/CIRCLE/workingpapers/200818_Yun-Chung_et_al.pdf
[298] Kathleen A. Walsh, "China R&D: A High Tech Field of Dreams," *Asia Pacific Business Review*, Vol. 13, No.3, July 2007, p. 321.
[299] *People's Daily Online*, "China home to 1,200 foreign R&D centers," March 16, 2010.
http://english.peopledaily.com.cn/90001/90778/90861/6921243.html

spending.[300] Of the world's Fortune 500 companies, over 400 have launched R&D centers on the Chinese mainland.[301] These operations now represent a sizable portion of all Chinese corporate and national R&D. The Ministry of Commerce says that foreign companies increased their share of total R&D expenditure in large and mid-sized manufacturing from 19.7 percent in 2002 to 27.2 percent in 2008. As a result of this activity, foreign firms hold 29 percent of all invention patents in China.[302]

Many of these foreign R&D centers primarily adapt foreign technology to China's market, or focus on tailored product development. Yet evidence suggests a trend towards high-end research. This shift is visible in the fact that these R&D centers increasingly function as Asian and even global innovation centers. For example, Microsoft founded "Microsoft Research China" in Beijing in 1998, upgraded it to "Microsoft Research Asia" in 2001, and opened the Shanghai Science and Technology Park in 2010 as its only comprehensive research center outside of the United States. Similarly, Hewlett-Packard's HP Labs China was established in 2005 as the company's sixth global laboratory, where it conducts joint R&D with Chinese universities and research institutes.[303] Motorola's Global Telecom Solutions Sector China Design Center is its second largest center of its kind, smaller only than the one in the United States.[304] And GE's China Technology Center in Shanghai is one of four overseas R&D centers in the company's Global Research program (the others being in Bangalore, Munich, and Rio de Janeiro), which support GE business around the world.[305]

China has employed various methods to attract R&D centers and to try to ensure that they benefit China's technological growth. The PRC government encourages MNCs to set up R&D centers in high-tech development zones such as Beijing's Zhongguancun. Local governments and development zone authorities compete with each other to attract foreign investors, offering modern infrastructure, and even a period of free rent, favorable lease terms and construction loan assistance.[306] Companies are often given a tax holiday until a few years after turning profits, and receive reduced taxes for a period afterwards, as well as tax exemptions on equipment imports. Research centers can also receive government subsidies for their R&D activities.[307]

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[300] *Science and Engineering Indicators 2010*, Chapter 4, p.6.
http://www.nsf.gov/statistics/seind10/pdf/c04.pdf

[301] *Jianmin Jin, "Foreign Companies Accelerating R&D Activity in China" Fujitsu Research Institute, May 13, 2010. http://jp.fujitsu.com/group/fri/en/column/message/2010/2010-05-13.html*

[302] Also, foreign companies accounted for 21 percent (2006) of all R&D centers in large and mid-sized manufacturing and 19 percent of the entire R&D workforce (2006). Jianmin Jin, "Foreign Companies Accelerating R&D Activity in China" *Fujitsu Research Institute*, May 13, 2010.
http://jp.fujitsu.com/group/fri/en/column/message/2010/2010-05-13.html

[303] HP, "HP, Tsinghua University Form Multimedia Research Center in Beijing," May 31, 2007.
http://www.hpl.hp.com/china/news/20070531.html

[304] Motorola, "Motorola China R&D Institute." http://www.motorola.com.cn/en/about/inchina/joint.asp

[305] General Electric, http://ge.geglobalresearch.com/locations/shanghai-china/about/

[306] Kathleen Walsh, "Foreign High-tech R&D in China: Risks, Rewards, and Implications for U.S.-China Relations," The Henry L. Stimson Center, 2003, p. 90.

[307] *Jianmin Jin, "Foreign Companies Accelerating R&D Activity in China" Fujitsu Research Institute, May 13, 2010. http://jp.fujitsu.com/group/fri/en/column/message/2010/2010-05-13.html*

R&D centers also serve as political currency for multinational firms, which often believe they need them to be effective in conducting business in China. According to US Naval War College Professor Kathleen Walsh, some companies have established an R&D presence in China "to appease PRC officials who demand it" and to "[further] other, long-term interests in the China market."[308] MNCs seek collaborations with China's leading universities and research institutions, not only to leverage the university's assets and get access to the brightest students for future employment, but the ability to build relationships with government officials and gain insights on government policies. For example, telecom companies have signed numerous technology transfer agreements and joined R&D programs with the Beijing University of Posts and Telecommunications (BUPT) because of its important links to telecommunications regulators in the capital.[309]

MNC R&D centers have had mixed effects on China's technological development. Their "spillover" benefits for China are hotly debated in Chinese academic and government circles, with critics arguing that most of the benefits flow to the global business operations of the MNCs. On the one hand, MNC innovation activities can hamper China's indigenous development by attracting the best researchers from local companies, universities and research institutes.[310] To attract and retain talent, China's top research institutes have had to raise salaries and benefits. MNCs' technological advantages may also deter local firms from pursuing competitive technology development in order to collaborate with the MNCs. A typical situation in which foreign MNCs concentrate on technology innovation while local companies focus on distribution can create technological dependency.[311]

On the other hand, the localization of MNC R&D in China provides clear benefits to China. MNC R&D centers offer demonstration effects and competition for Chinese firms, pushing them to establish research laboratories of their own. The possibility for labor mobility among MNC R&D centers, Chinese research institutions, and local firms allows for the transfer of western R&D management practices and technical knowledge to spread beyond the MNCs. Chinese researchers in MNC R&D centers form technological communities that, in principle, could then be harnessed by Chinese firms to re-innovate and develop products under their own brands.[312] Foreign companies are certainly mindful of the spillover and technology leakage problems associate with research and production in China, and attempt to develop strategies to deal with them.[313]

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[308] Kathleen A. Walsh, "China R&D: A High Tech Field of Dreams," *Asia Pacific Business Review*, Vol. 13, No.3, July 2007, p. 323.
[309] Kathleen Walsh, "Foreign High-tech R&D in China: Risks, Rewards, and Implications for U.S.-China Relations," The Henry L. Stimson Center, 2003, p. 83.
[310] Jianmin Jin, "Foreign Companies Accelerating R&D Activity in China" *Fujitsu Research Institute*, May 13, 2010. http://jp.fujitsu.com/group/fri/en/column/message/2010/2010-05-13.html
[311] Yen-Chung Chen, "The Upgrading of Multinational Regional Innovation Networks in China," *Asia Pacific Business Review* Vol. 13, No. 3 (July 2007), pp. 398-390.
[312] Yen-Chung Chen, "The Upgrading of Multinational Regional Innovation Networks in China," *Asia Pacific Business Review* Vol. 13, No. 3 (July 2007), pp. 398-390.
[313] Xiaohong Quan and Henry Chesbrough, "Hierarchical Segmentation of R&D Process and Intellectual Property Protection; Evidence from Multinational R&D Laboratories in China," *IEEE Transactions On Engineering Management,* Vol 57, No. 1, February, 2010, pp. 9-21.

Chinese authorities remain convinced that by tapping into the global R&D ecosystem through foreign research centers established in China, they can close technology deficits. Taking the semiconductor sector as an example, Chinese policy statements repeatedly emphasize the need to attract foreign R&D efforts, especially as R&D spending by US semiconductor companies is expected to flow outward in coming years. A survey of US semiconductor companies shows that in the United States, domestic R&D will drop from 78 percent of total R&D expenditures in the 2005 to 2007 period to 69 percent of total expenditures in the 2009 to 2013 period. Europe will pick up most of that slack, but China, too, will benefit, rising from 1 percent of US R&D spending in semiconductor technology to 2.2 percent.[314] A few examples of increasing R&D efforts in China by American companies include:

- Intel investing $2.5 billion in a 300mm wafer fabrication plant in Dalian (Fab 68) to open in October 2010, along with $250 million spent on 67 projects in China.[315]
- AMD launching the Shanghai Research and Development Center in 2006 to focus on the development of its next-generation mobile platforms.[316]
- Freescale opening a design center in Chengdu in 2007 to serve as its "primary operations for the development of TD-SCDMA technologies."[317]
- Intersil opening a design and application center in Hangzhou in 2008 to develop reference designs for its analog semiconductors.[318]
- Semtech opening a design and application center in Shenzhen in 2008 for its advanced communications and sensing products.[319]

Nevertheless, China's hopes for a transformative effect on China's semiconductor industry through foreign R&D investments have yet to be borne out. The inadequacy of intellectual property protection in China, and US government export restrictions on technologies with military applications, are significant factors in constraining the expansion in China of US R&D spending in cutting edge technologies. In the semiconductor industry, most multinational semiconductor companies seem to have made a strategic decision not to part with their critical intellectual property. While Intel's Fab 68 will produce relatively sophisticated equipment with large 300-millimeter wafers for

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[314] Dewey & LeBoeuf for the Semiconductor Industry Association, "Maintaining America's Competitive Edge: Government Policies Affecting Semiconductor R&D and Manufacturing Activity," White Paper, March 2009, p. 23.
[315] David Barboza, "Intel to Make Chips in China," *New York Times*, March 26, 2007 http://www.nytimes.com/2007/03/26/business/worldbusiness/26iht-chip.5.5034688.html; 51nb.com, "Xiaoxi Cheng Intel Dalian Fab 68 Gongchang 10 Yue Zhengshi Touchan" (Reports say Intel's Dalian Fab 68 will go into Formal Production in October), Chinabyte.com, March 19, 2010. http://nbpc.chinabyte.com/494/11179494.shtml
[316] AMD, "AMD history." http://www.amd.com/us/aboutamd/corporate-information/Pages/timeline.aspx
[317] Freescale was subsequently purchased by a Chinese firm. Dewey & LeBoeuf for the Semiconductor Industry Association, "Maintaining America's Competitive Edge: Government Policies Affecting Semiconductor R&D and Manufacturing Activity," White Paper, (March 2009). p. 32.
[318] *EE Times Asia*, "Intersil opens new design center in Hangzhou, China," Mar 3, 2008. http://www.eetasia.com/ART_8800507554_480100_NT_f6bf7a42.HTM
[319] *Power Electronics Technology*, "Semiconductor Vendor Adds Design Center in Shenzhen," August 13, 2008. http://powerelectronics.com/power_management/news/semiconductor-vendor-adds-design-center-0813/

chip sets, Intel will not transfer to China major secrets regarding its powerful microprocessing chips, and its process technology will already be two generations ahead when the plant opens.[320] A limited number of Taiwan, European and Korean semiconductor firms have also engaged in front-end manufacturing activities in China, but these too do not employ leading-edge technology.[321]

Thus, there is considerable debate about the impacts of R&D centers, reflecting tensions between techno-nationalism and techno-globalism as innovation networks become increasingly intertwined. PRC government policy has been welcoming of foreign R&D efforts in the belief that they provide China with critical experience in the management of R&D in the kinds of science-based industries China sees as the future of its industrial economy, and will lead to significant knowledge transfers as employees migrate out of the MNCs to join Chinese enterprises or start their own companies. Critics argue that most of the benefits of these R&D centers go to the MNCs and their global operations, which exploit the best of Chinese research talent for their commercial gain.[322] On the US side, companies defend their need to compete and innovate, but critics worry that China-based R&D centers lead to technological leakage that will come back to haunt them and further erode the US's R&D base.

Outbound Mergers and Acquisitions

Another channel for the PRC to acquire technology is through the purchase of foreign companies, allowing Chinese firms to harness their intellectual property and networks of talent.[323] So far, the targets of most outbound Chinese investment are companies with oil, gas and mineral resources whose control Beijing has deemed critical to its economic growth. But high technology, manufacturing and service industries are now receiving more attention in China's acquisition strategy, says PricewaterhouseCooper's David Brown.[324]

While relatively small thus far, China's technology-intensive acquisition activity in the United States has received substantial media attention. These include Lenovo's purchase of IBM's personal computer unit in 2005 and Geely Auto's purchase of Volvo Cars from the Ford Motor Company in 2010. In 2005, the China National Offshore Oil Corp. (CNOOC) attempted to acquire US oil company Unocal for $18.4 billion before withdrawing under pressure from US lawmakers. Huawei was also reportedly in

[320] David Barboza, "Intel to Make Chips in China," *New York Times*, March 26, 2007 http://www.nytimes.com/2007/03/26/business/worldbusiness/26iht-chip.5.5034688.html,

[321] Falan Yinug, "Challenges to Foreign Investment in High-tech Semiconductor Production in China," Journal of International Commerce and Economics, United States International Trade Commission, web version, May 2009, 14-15.

[322] Interviews with author, Beijing, 2008.

[323] According to an economist with the State Council's Development Research Center, Chinese officials support acquisitions of foreign companies because they allow Chinese domestic companies to quickly acquire "resources, technology, brands and sales channels." *Xinhua*, "Trials and tribulations of foreign mergers and acquisitions," posted in China Daily, December 12, 2009. http://www.chinadaily.com.cn/bw/2009-12/28/content_9235097.htm

[324] PricewaterhouseCoopers , "China outbound M&A deal activity up by more than 50 percent," http://www.pwc.com/gx/en/press-room/2010/china-outbound-MA-deal-activity-up.jhtml

competition to buy Motorola's wireless division in 2010 before it was scooped up by Nokia.[325]

To put technology acquisition in perspective, 80 percent of the value of China's outbound M&A from 2003 to the 3rd quarter of 2009 was in energy or financial-related acquisitions, with seven percent in Technology, Media and Telecommunications (TMT) companies, six percent in industrials, and just one percent on pharmaceuticals, medical and biotech firms.[326] A list of the nine largest acquisitions of US technology companies shows a relative paucity of major deals.

Figure 13: Largest outbound acquisitions into the US involving technology-related companies (through third quarter of 2009)[327]

Value Rank	Announced date	Target Company (USA)	Target Sector	Bidder Company (China/HK)	Seller Company (USA)	Deal value (US$m)
1	May-05	IBM Corporation (Personal Computing Division)	Computer: Hardware	Lenovo Group Ltd	IBM Corporation	1,750
2	Aug-10	Volvo Cars	Automotive	Geely Holding Group	Ford Motor Co.	1,500
3	Mar-08	Datascope Corporation (patient monitoring business)	Medical	Mindray Medical International Ltd	Datascope Corporation	240
4	Sep-07	Sino-American Energy Corporation	Energy	Singapore Petroleum (china) Private Ltd	Ultra Petroleum Corp	223
5	Jan-08	AppTec Laboratory Services, Inc	Biotechnology	WuXi PharmaTech	N/A	163
6	Feb-04	First International Oil Corp	Energy	Sinopec International Petroleum Exploration and Production Corporation	N/A	153
7	Jan-08	China Hydroelectric Corporation	Energy	Merrill Lynch (Asia Pacific) Ltd	N/A	150
8	Mar-09	Delphi Corporation (Global Suspension and Brakes business)	Automotive	Beijing West Industries Co Ltd	Delphi Corporation	100
9	Apr-09	Freescale Semiconductor (mobile phone chip division)	Computers: Semiconductors	Qiao Xing Mobile Communication Co Ltd	Freescale Semiconductor Inc	100

[325] *Anupreeta Das and Sara Silver, "Motorola Sells Networking Unit for $1.2 Billion," The Wall Street Journal, July 19, 2010. http://online.wsj.com/article/SB10001424052748704196404575375230677651488.html*
[326] Deloitte and mergermarket, "The Emergence of China: New Frontiers in Outbound M&A ," Global Chinese Services Group, November 2009. http://www.deloitte.com/assets/Dcom-China/Local%20Assets/Documents/Services/Global%20Chinese%20Services%20Group/cn_gcsg_EmCnNewFront_011209.pdf
[327] Deloitte and mergermarket, "The Emergence of China: New Frontiers in Outbound M&A ," Global Chinese Services Group, p. 26; Volvo Cars. http://www.volvocars.com/intl/top/about/news-events/pages/default.aspx?itemid=193

Despite the precedent of little investment in technology companies overseas, the financial crisis left in its wake a number of capital-strapped foreign enterprises with valuable patented technologies. Recognizing an opportunity, the Chinese central government unveiled policies to encourage outbound M&A of technology enterprises. The Implementation Rules for the Plan on Adjusting and Revitalizing the Equipment Manufacturing Industry, for example, included items "to encourage qualified enterprises to merge with or regroup overseas enterprises and research institutes," and a provision encouraging discounted loans for these activities.[328]

China's state banks have proved ready to step in with the necessary capital for state-sanctioned acquisitions.[329] The China Development Bank's $30 billion loan to China National Petroleum Corp in 2009 is but one example of the preferential loan and credit arrangements used to enhance the war chests of Chinese companies looking for overseas deals.[330]

Despite the favorable policy climate in China, the PRC's acquisition of foreign technology companies still faces obstacles. Private Chinese businessmen balk at overseas M&A, a *Xinhua* article notes.[331] Fledgling Chinese technology companies find the task of integrating a foreign company a daunting challenge, while retaining the talent of an acquired company—the most important resource of high-tech firms—is seen as difficult. Differences in culture, processes, and legal systems, combined with the relative immaturity of Chinese management in running the complex innovation system of a large multinational corporation have put a damper on hopes of Chinese officials to simply acquire technology abroad.[332]

In addition, when considering the acquisition of companies in the United States, Chinese buyers have to take into account the attitudes of lawmakers and the need to receive approval from the Committee on Foreign Investment in the United States (CFIUS), which vets foreign acquisitions of American companies on their national security implications. CFIUS investigates about 10 percent of cross-border deals every year,[333] and has had significant influence in discouraging deals from China involving cutting edge technology.

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[328] Ivan Lee, "Overseas M&A: Technologies More Important than Resources," Zero2ipo, May 27, 2009. http://www.zero2ipo.com.cn/en/n/2009-5-27/2009526141816.shtml
[329] *Xinhua*, "Trials and tribulations of foreign mergers and acquisitions," posted in China Daily, December 12, 2009. http://www.chinadaily.com.cn/bw/2009-12/28/content_9235097.htm
[330] Deloitte and mergermarket, "The Emergence of China: New Frontiers in Outbound M&A ," Global Chinese Services Group,
[331] *Xinhua*, "Trials and tribulations of foreign mergers and acquisitions," posted in China Daily, December 12, 2009. http://www.chinadaily.com.cn/bw/2009-12/28/content_9235097.htm
[332] *Xinhua*, "Trials and tribulations of foreign mergers and acquisitions," posted in China Daily, December 12, 2009. http://www.chinadaily.com.cn/bw/2009-12/28/content_9235097.htm
[333] Deloitte and mergermarket, "The Emergence of China: New Frontiers in Outbound M&A ," Global Chinese Services Group, p. 26

US Universities, Returnees and Technology Transfer

One of the US's largest contributions to Chinese science has undoubtedly been the training and development of Chinese talent in its universities and research institutes. These students have competed with the most accomplished students in America's top universities. They are also part of a growing interdependence in US and Chinese science, as many of the students are highly demanded by American companies, and welcomed by American universities where they perform research and fund their education largely without university financial support.

According to the NSF's Science and Engineering Indicators, the number of Chinese nationals enrolled in science and engineering concentrations in American graduate school programs in April 2009 numbered 36,890, second only to India. Chinese students enrolled in large numbers in engineering (13,110), physical sciences (6,070) biological sciences (5,290), computer sciences (3,970), and mathematics (3,840).[334] The concentration of Chinese students in American science programs is even greater when considering doctorate degrees. From 1987 to 2007, US universities awarded 50,200 doctorate degrees in science and engineering to Chinese citizens, and experienced a tenfold increase in Chinese students over that period.[335] In 2008 the 4,526 doctorate recipients who were citizens of China (including Hong Kong) represented 10 percent of the total number of doctorate degrees awarded to all respondents to the NSF survey, more than any other foreign country.[336]

Upon graduation, the majority of Chinese graduate students in science and engineering remain in the United States where they contribute to American science through academic research and corporate R&D. At the same time, these Chinese nationals are also acquiring valuable skills and building networks that can enable their success in the development of China's science and industry. Many Chinese do return to China at some point in their careers to take positions in universities, start companies, or join Chinese or foreign multinational firms. According to the latest available statistics from China's Ministry of Education, from 1978 to 2003, 700,200 Chinese students studied outside the mainland. Over the same period 172,800 returned to China and 527,400 remained abroad.[337]

From these and other statistics, it does appear that the United States has been successful in attracting and retaining Chinese students, many of whom have gone to work in American companies and universities. From 2004 to 2007, more than 90 percent of US

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[334] National Science Foundation, "Higher Education in Science and Engineering," Science and Engineering Indicators 2010, Appendix table 2-19: "Foreign graduate student enrollment in U.S. universities, by field and selected places of origin: April 2008 and 2009."
[335] National Science Foundation, "Higher Education in Science and Engineering," 2-27. http://www.nsf.gov/statistics/seind10/pdf/c02.pdf
[336] National Science Foundation, "Doctorate Recipients from U.S. Universities: Summary Report 2007-08," December 2009. http://www.nsf.gov/statistics/nsf10309/pdf/nsf10309.pdf
[337] 356,600 are still studying, doing researches or visiting as scholars in foreign HEIs. PRC Ministry of Education, "Work Related to Students and Scholars Studying Abroad," July 25, 2008. http://www.wei.moe.edu.cn/article.asp?articleid=2666

science and engineering doctoral recipients from China reported plans to stay in the United States, with more than half reporting that they accepted offers for employment or to do postdoctoral research in the United States. Though representing a slight decline from previous years (see Figure 14), the rate of respondents claiming an intention to remain was higher than those of all other groups of foreign nationals.[338] Chinese doctoral students who completed their PhDs in 2000, 92 percent of were still in the United States five years later, a rate of remain that has changed little since the early 1990s (see Figure 15).

Figure 14: Percentage of Chinese citizen and all non-US citizen science and engineering doctorate recipients with plans to stay in the US after graduation[339]

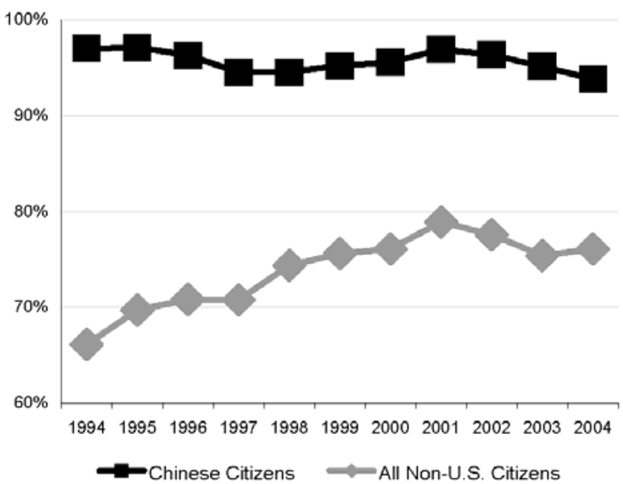

Figure 15: Percentage of Chinese Foreign Students on Temporary Visas Receiving S&E Doctorates Who Were in the United States 4 to 5 Years after Graduation, for Selected Years, 1992-2005[340]

1987/88 Doctorate Recipients in 1992	1990/91 Doctorate Recipients in 1995	1992/93 Doctorate Recipients in 1997	1994/95 Doctorate Recipients in 1999	1996 Doctorate Recipients in 2001	1998 Doctorate Recipients in 2003	2000 Doctorate Recipients in 2005
65	88	92	91	96	90	92

[338] National Science Foundation, "Higher Education in Science and Engineering," Science and Engineering Indicators 2010, 2-27. http://www.nsf.gov/statistics/seind10/pdf/c02.pdf
[339] Source: Survey of Earned Doctorates, special tabulation by the National Science Foundation, August 2006, chart from Aaron D. Levine, "Trends in the Movements of Scientists between China and the United States and Implications for Future Collaborations," Proceedings of the China-U.S. Forum on Science and Technology Policy, 329. http://www.law.gmu.edu/nctl/stpp/pubs/SectionIV.pdf
[340] Michael G. Finn, "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2005," 2007, pp. 8-9. http://blogs.knoxnews.com/munger/030508stay.pdf.

Ever since the 1980s as the number of Chinese studying abroad increased, the Chinese government has been continuously concerned by this "brain drain" of China's talent. As noted on pages 37 and 38, the Chinese government has multiple programs to encourage American-trained Chinese scientists and engineers to return to China and bring with them advanced scientific knowledge and—perhaps more importantly—the tacit knowledge of research strategies and techniques that cannot be found in scientific journals.[341]

Local governments have also become active in trying to encourage overseas scholars to locate in their cities and reward those who bring back new technology. For example, the Guangzhou Returnees' Fair held every December grew out of the Guangzhou government's efforts and now operates on a national scale. The fair encourages overseas researchers to link their technological projects with domestic firms or high tech zones. Representatives from high tech zones and the Returnees' Services Centers (*Huiguo renyuan fuwu zhongxin*) in most major cities attend the fair, hoping to attract overseas projects or overseas scholars.[342]

China has had only mixed success in its various attempts to lure back its talent. Many Chinese continue to pursue careers abroad while the way returned Chinese expatriates ("returnees") have been used at home is occasionally controversial. Many researchers given material incentives and honorific positions to return to universities and institutes have not fulfilled the obligations of their appointments. Chinese institutions are often content to use the names of these returned scientists to improve their evaluations and qualify for government funding.[343]

Still, returnees are playing a major role in China's scientific and technological development. Most university presidents and institute leaders have had foreign training, if not foreign advanced degrees, and a number of returnees are also assuming important leadership roles in local and provincial governments. Chinese returnees while abroad will often obtain knowledge of a technology that is common in the United States but in short supply in China, providing the possibility of "extra-normal profits" when they return. Such entrepreneurs may return to a research institute or set up their own companies, often in a high-tech research park. Others may set up a company in China while remaining abroad, or transfer technology through their social networks in China.[344]

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[341] David Zweig, "Returnees, Technology Transfer, and China's Economic Development," Center on China's Transnational Relations Working Paper No. 28, June 2009, p. 4. http://www.cctr.ust.hk/materials/working_papers/WorkingPaper28-DZ-Returnees_and_Tech_Transfer.pdf

[342] David Zweig, "Returnees, Technology Transfer, and China's Economic Development," Center on China's Transnational Relations Working Paper No. 28, June 2009, pp. 5-6. http://www.cctr.ust.hk/materials/working_papers/WorkingPaper28-DZ-Returnees_and_Tech_Transfer.pdf

[343] Cong Cao, Richard P. Suttmeier, and Denis Fred Simon, "China's 15 Year Science and Technology Plans," *Physics Today*, December, 2006.

[344] David Zweig, "Returnees, Technology Transfer, and China's Economic Development," Center on China's Transnational Relations Working Paper No. 28, June 2009, p. 4. http://www.cctr.ust.hk/materials/working_papers/WorkingPaper28-DZ-Returnees_and_Tech_Transfer.pdf

Around 6,000 returnees were working in technology development zones in 2005. In US MNC-owned R&D centers in China, most major employees are returnees.[345] As of 2000, the majority of academics in the Chinese Academy of Sciences had spent time abroad as visiting scholars or students, and returnees play leading roles as institute directors and as presidents and department heads at universities. Studies show that returnees do much better in receiving grants, transferring new Western ideas, and establishing international projects than those who have not. [346]

Links Between US and Chinese Scientists and Research Institutions

At the core of China's international scientific contacts are the thousands of activities occurring at the scientist-to-scientist level. This is consistent with the traditional culture of academic science, as researchers seek out colleagues with common interests with whom they can share findings, collaborate or, perhaps, compete. These relationships between and among scientists have been powerfully influenced by the ties that have developed as a result of Chinese students doing graduate work abroad. Mentor-student relations involve research collaboration that over time evolves into senior colleague-junior colleague collaboration.

As noted, a large number of Chinese students who have come to the US have stayed and taken professional employment in US universities, companies and government laboratories. At the same time, these individuals have often maintained ties with colleagues at institutions in China, which has also fostered collaboration. When one examines the international co-authoring of China-based researchers, collaborations with US colleagues clearly outnumber those with other countries.[347] Reportedly, nearly 40 percent of China's science and engineering publications in international journals had US-based co-authors. On the US side, some 8 percent of papers had China-based co-authors.[348] While it may be premature to discuss the emergence of "Chimerican" science,[349] it is nevertheless evident that a deepening interdependency in academic science is developing between the two countries.

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[345] Yun-chung Chen, "Limits of Brain Circulation: Chinese Returnees and Technological Development in Beijing," Center on China's Transnational Relation, Working Paper No. 15, 2006-2007, p. 4. http://www.cctr.ust.hk/materials/working_papers/WorkingPaper15.pdf; Chen Yun-Chung, Jan Vang and Cristina Chaminade, "Regional Innovation Systems and the Global Location of Innovation Activities: Lessons from China," Paper No. 2008/18, p. 12. http://www.lu.se/upload/CIRCLE/workingpapers/200818_Yun-Chung_et_al.pdf

[346] David Zweig, "Returnees, Technology Transfer, and China's Economic Development," Center on China's Transnational Relations Working Paper No. 28, June 2009, pp. 5-6. http://www.cctr.ust.hk/materials/working_papers/WorkingPaper28-DZ-Returnees_and_Tech_Transfer.pdf

[347] Bihui Jin, Ronald Rousseau, Richard P. Suttmeier, Cong Cao. "The Role of Ethnic Ties in International Collaboration: The Overseas Chinese Phenomenon," in D.Torres-Salinas and H.F. Moed (eds.) *Proceedings of the ISS,*. 2007, CSIC, Madrid, pp. 427-436. http://china-us.uoregon.edu/papers.php.

[348] Norman P. Neureiter and Tom C. Wang, "US-China S&P at 30," *Science*. Vol. 323 (January 30, 2009). p. 687.

[349] A term coined by Niall Ferguson and Moritz Schularick to describe the significance of the China-US financial interdependence for the world economy.

Consider the case of cooperation in nano-science described earlier, that has seen co-authored papers involving Americans and Chinese in nano-science grow from 16 in 1996 to 293 in 2005. A likely that part of the explanation for this increase is that a good number of Chinese scientists who remained in the US after graduate training had established careers by 2005 and sought to expand collaboration with colleagues in China. The fact that nano research has been an area of rapid development in China as a result of China's robust support for the field makes collaboration with China in this field all the more attractive.[350]

Further evidence of a growing interdependency between the technical communities of the two countries is the growth of more institutionalized relations between US universities and Chinese counterparts. US universities have been somewhat slow in establishing formal research relationships with Chinese universities, but this is beginning to change. For example, Texas A&M University has initiated its China-US Relations Conferences[351] and UC Santa Barbara has launched a partnership with the CAS Dalian Institute for Chemical Physics (DICP), an internationally recognized center for research on catalysis, and a handful of other advanced institutes.[352] The Harvard China Project of the Harvard School of Engineering and Applied Sciences and Harvard University Center for the Environment are connected with key Chinese universities in the field of environmental studies. An ambitious new initiative to build inter-institutional cooperation is the "10+10 Alliance," a proposal (now on hold for budgetary reasons) for collaborative research and education between the10 campuses in the University of California system, and ten leading Chinese universities.[353]

Another interesting case of a new institutional initiative is the Peking-Yale Joint Research Center for Plant Molecular Genetics and Agro Biotechnology, a collaboration between the Department of Molecular, Cellular and Developmental Biology at Yale and the College of Life Sciences at Peking University. The center is led by Xing-wang Deng, a member of the Yale faculty who also holds a Changjiang Scholar appointment at Peking University.[354] Yale also collaborates with Shanghai's Fudan University on research involving genetic links to neurophysiological and immunological problems. The schools maintain two interdependent labs on their campuses and the Fudan laboratory is taking the lead on a massive program to create genetically modified mice, whose costs are planned to be only one fifth to one fourth of what it would cost in the United States.[355]

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[350] Richard P. Suttmeier, "State, Self-Organization, and Identity in the Building of Sino-US Cooperation in Science and Technology," *Asian Perspective* 32, 1, 2008.
[351] See, Texas A&M US-China Relations Conference. http://china-us.tamu.edu/2009-conference-materials/conference-program
[352] The UCSB-DICP relationship is one of several next-generation projects with China supported by the NSFs Partnership for International Research and Education (PIRE) program noted above. UC Santa Barbara, "UCSB Awarded Additional $4 Million by the National Science Foundation For Research and Training Partnership with China," August 9, 2010. http://www.ia.ucsb.edu/pa/display.aspx?pkey=2302
[353] University of California at Davis. http://uoip.ucdavis.edu/documents/10+10_overview.pdf
[354] Peking University. http://www.pyc.pku.edu.cn/index.html
[355] Aaron D. Levine, "Trends in the Movements of Scientists between China and the United States and Implications for Future Collaborations," Proceedings of the China-U.S. Forum on Science and Technology Policy, 331. http://www.law.gmu.edu/nctl/stpp/pubs/SectionIV.pdf; *Science* 30 June 2006: Vol. 312. no. 5782, p. 1864;

To the authors' knowledge, there is no comprehensive listing of inter-institutional research activities between US and Chinese universities, but a sampling of cases would include the following:

Figure 16: Scientific Links between US and Chinese Universities

US University	Chinese University	Program Description	Founded
Harvard School of Engineering and Applied Sciences	Tsinghua University, Hong Kong Polytechnic University, Beihang University, Sichuan University	Harvard China Project (Collaborative research on atmospheric sciences)	1996
George Mason University	Chinese Academy of Sciences Peking University	Program of US-China Cooperation in Science Policy, Research and Education[356]	1998
The Levin Institute, State University of New York	Dalian Maritime University Wuhan University of Science and Technology	Center for Science, Technology, and Innovation in China[357]	1999
Yale University	Peking University	Joint Research Center for Plant Molecular Genetics and Agro Biotechnology[358]	2001
University of Houston Medical Center	Qingdao University	China-US Stem Cell Research Center[359]	2004
Indiana University–Purdue University Indianapolis	Sun Yat-Sen University	Drug and Food Safety and partnerships with pharmaceutical companies[360]	2006
University of California at Santa Barbara	Dalian Institute of Chemical Physics, Tsinghua University, Fudan University, Xiamen University, others	Partnership for International Research and Education: Advancing the U.S.-China Partnership in Electron Chemistry and Catalysis at Interfaces[361]	2007

http://info.med.yale.edu/genetics/xu/index.php?option=com_content&task=view&id=16&Itemid=41
[356] George Mason University, "Program of U.S.-China Cooperation in Science, Policy, Research and Education," http://www.law.gmu.edu/nctl/stpp/pubs/GMUChinaProgramSummary.pdf
[357] Levin Institute, "Center for Science, Technology and Innovation in China," http://www.levininstitute.org/cstic.cfm
[358] Peking University. http://www.pyc.pku.edu.cn/index.html
[359] Qingdao University, "Qindao daxue Zhong-Mei gan xibao yu zaisheng yixue zhongxin" (Qingdao University Stem Cell and Regenerative Medicine Center). http://qdumh.qd.sd.cn/qyfy/a3/ShowArticle.asp?ArticleID=133.
[360] Sara Hebel, "Thinking Locally, Acting Globally," *The Chronicle of Higher Education*, Vol. 53, Issue 43, Page A38. http://www.csun.edu/pubrels/clips/June07/06-25-07X.pdf
[361] UC Santa Barbara, "UCSB Awarded Additional $4 Million by the National Science Foundation For Research and Training Partnership with China," August 9, 2010. http://www.ia.ucsb.edu/pa/display.aspx?pkey=2302

University of Texas at Arlington	China University of Geosciences	"Trenchless Technology and Critical Underground Infrastructure Issues"[362]	2007
Yale University	Fudan University	Joint labs producing knockout mice.	2007
West Virginia University, University of Wyoming, University of Kentucky, Indiana University	Multiple, including Chinese companies and research institutes.	Clean coal consortium, part of the US-China Clean Energy Research Center (CERC)[363]	2010
University of Michigan, Ohio State University, MIT	Multiple, including Chinese companies and research institutes.	Clean vehicle consortium of CERC[364]	2010
MIT, University of California at Davis	Multiple, including Chinese companies and research institutes.	Energy-efficient buildings consortium of CERC	2010

US-China Scientific Cooperation

The PRC believes in the importance of government-supported science and technology linkages and has committed generous resources to enhance them. China's various science agencies maintain well staffed international offices with dedicated budgets for international cooperation. Although international cooperation was not explicitly highlighted in the MLP, MOST nevertheless increased funding for international activities substantially since the MLP period began, and provincial and local governments have increasingly focused on internationalizing their S&T activities.

Over the years, the international cooperation offices of China's science agencies have facilitated the development of international ties spanning the academic, commercial and government realms. In the latter, China has developed and maintained active government to government programs with a number of other countries, including Japan, and with the EU, as well as those with the United States.

European nations have been willing to spend fairly generously on the relationship, and have given it more political attention than the United States has in recent years. Still, the government to government S&T relationship with the United States remains an important one for China, and of growing importance for the US. The relationship is based on the 1979 *Agreement on Cooperation in Science and Technology*, which committed the two sides to encourage and facilitate contacts and cooperation between government

[362] TT Staff, "U.S.-China Collaboration Helps Spread the Reach of Trenchless Technology," *Trenchless Technology International*, November 2007. http://www.trenchlessonline.com/index/webapp-stories-action?id=133

[363] *WVU Today*, "WVU leads US-China research efforts for clean coal, carbon capture technologies," September 2, 2010, http://wvutoday.wvu.edu/n/2010/9/2/wvu-leads-us-china-research-effort-for-clean-coal-carbon-capture-technologies

[364] "China-US collaboration on clean energy research," Physorg.com, September 9, 2010, http://www.physorg.com/news203227418.html

agencies, universities, and other institutions for the mutual benefit of their nations.[365] After thirty years, the *Agreement* now has some 26 subordinate agency to agency protocols and various other institutional strands. The asymmetry in capabilities that characterized it at the outset has given way to growing interdependence, brought about by the globalization of scientific innovation and China's remarkable scientific progress over this time. Cooperation has also been stimulated in recent years by the shared interest in engaging on the scientific challenges related to climate change, energy, sustainable development and health.[366] Energy and environment cooperation are discussed here, while a sampling of other joint activities can be found in Appendix III.

Energy and Environment

Sino-US cooperation in the fields of energy and environmental science and technology has intensified considerably as the Obama administration has emphasized the dual roles of the United States and China in climate change. Their cooperation in these areas, in many ways, represents the core of their bilateral science activities and are important programs in the US-China Strategic and Economic Dialogue (S&ED), and the earlier Strategic Economic Dialogue (SED) process.

Energy and environment issues were added to the agenda of the Strategic Economic Dialogue (SED) during the second term of the Bush administration and led to the signing of a Memorandum of Understanding (MOU) for a "Ten Year Framework for Energy and Environment Cooperation" signed in late 2008.[367] The Framework provides for intensified cooperation in areas of electric power generation, transportation, clean water, clean air, and wetland preservation. At the Fifth SED, energy efficiency was added to the framework as a fifth area of focus, and enlists the US Trade and Development Agency (TDA) and the US Export-Import Bank to support private sector activities in addressing "deficiencies in energy efficiency in Chinese enterprises" and to assist in the implementation of the clean water program.

At the first meeting under the new Strategic and Economic Dialogue (S&ED) between senior representatives of the Obama administration and Chinese counterparts in July 2009, the Ten-Year Cooperation Framework (TYF) was reaffirmed in a new MOU to "Enhance Cooperation on Climate Change, Energy and the Environment." Well before the July 2009 signing of MOU and the establishment of the new US-China Clean Energy Research Center, a variety of activities were well on course under a number of different agreements, including through:[368]

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[365] "United States of America and China Agreement on Cooperation in Science and Technology," United Nations No. 18102, November 14, 1979. untreaty.un.org/unts/60001_120000/2/25/00003216.pdf
[366] Richard P. Suttmeier, "State, Self-Organization, and Identity in the Building of Sino-US Cooperation in Science and Technology," *Asian Perspective* 32, 1, 2008.
[367] US Treasury Department Office of Public Affairs, Press releases. December 4, 5, 2008.
[368] The following discussion is based on Richard P. Suttmeier, "From Cold War Science Diplomacy to Partnering in a Networked World: 30 Years of Sino-US Relations in Science and Technology." Unpublished paper presented at the 2009 Hixon Forum, "Science and Technology in the Making of Modren China," Harvey Mudd College, February 27-28, 2009. http://china-us.uoregon.edu/papers.php

- A *Protocol For Cooperation in the Field of Fossil Energy Technology Development and Utilization* between DOE and MOST, originally signed in 2000 and renewed in 2005, includes annexes for cooperation in the areas of power systems (with China Power Investment Corporation); clean fuels (with NDRC); oil and gas (with China Petroleum and Chemical Industries Association); energy and environmental control technologies (with MOST), and climate science (with the Chinese Academy of Sciences and the China Meteorological Administration). Activities under these annexes involve training, R&D, demonstrations, and capacity building in areas of high global salience.

- Activities under the *Protocol for Cooperation in the Fields of Energy Efficiency and Renewable Energy Technology Development and Utilization* have also become especially salient. This protocol also has a series of annexes—for rural energy development, wind energy, energy efficiency, renewable energy business development, development of electric drive and fuel cell vehicle technologies, and renewable energy policy and planning. With the increasing attention being given to energy efficiency and to renewable energy technologies in China, the technology sharing, technical assistance, training, and business development under this protocol helps link the two countries in highly important areas of technology and policy. The US Department of Energy is also working with China in the area of biofuels under a memorandum of understanding with USDA and NDRC.

- In 1998, an agreement between DOE and NDRC on the peaceful uses of nuclear technologies was signed, with the China Atomic Energy Authority being the implementing agency on the Chinese side. The agreement calls for cooperation in such areas as nuclear technology, export controls, materials protection, control and accountability, safeguards, emergency management, and high-level radioactive waste management. The DOE activities in the nuclear safety area also augment activities under a protocol between the Nuclear Regulatory Commission and the Chinese National Nuclear Safety Administration (NNSA) which goes back to 1981, when NRC entered into an agreement with the State Science and Technology Commission (now the Ministry of Science and Technology-MOST). The NRC-NNSA agreement has taken on new life with China's decision to build Westinghouse AP-1000 power plants. Meanwhile, Chinese innovations in reactor design, especially its "pebble bed" reactor, are of considerable interest to the US side.

- As China pushes ahead with measures intended to ameliorate the environmental effects of burning coal, and as the United States struggles to develop a sound strategy for its own coal reliance, opportunities for cooperation in clean coal technologies are especially notable. China is requiring that new coal burning plants be equipped with supercritical or ultra supercritical generation technology, and has redoubled its efforts to develop commercial scale facilities for coal gasification and for CO2 capture and storage. MOST, with the Huaneng Group, set aside funds for participation in the DOE sponsored FutureGen project, which had been canceled by the Bush administration but now seems to be again funded by the new Economic Recovery Act.[369] As with the

[369] Deborah Seligsohn, "Can the US and China Cooperate on Coal?" *The Huffington Post*, January 28, 2009. http://www.huffingtonpost.com/deborah-seligsohn/can-the-us-and-china-coop_b_161204.html

"big science" facilities, noted earlier, China's increasing wealth gives it the wherewithal to build large facilities that are of considerable interest to the United States, including clean coal demonstration plants being built by the Huaneng and Shenhua companies, in cooperation with the Chinese government.

Building on this tradition of dialogue and cooperation, the United States and China agreed to the establishment of the US-China Clean Energy Research Center (CERC) during Energy Secretary Steven Chu's visit to China in July 2009. The new Center will focus on energy efficiency in buildings, clean coal technologies including carbon capture and storage, and clean vehicles. CERC represents a new direction in international cooperation and a significant new departure in US-China S&T relations. It involves the creation of university-industry-national lab consortia on both sides—for clean coal, clean vehicles and energy-efficient buildings—and includes serious budgetary commitments (often lacking in other US Government programs with China), with each side contributing $50 million to the Center (one half of which, on the US side, will come from the consortium members). The composition of the consortia reflects the breadth of the bilateral relationship and the complex new ways inter-institutional collaboration and international cooperation overlap in US-China S&T relations.

Illicit Technology Acquisition

Quite opposed to these instances of collaboration are instances of Chinese technology theft and espionage. Due to US export restrictions and licensing requirements on dual civilian and military use technologies and the reluctance of many firms to share certain technologies with China, PRC R&D entities—public and private—often find it necessary to fill capability gaps through illicit means. Chinese intelligence agencies, military research institutions and civilian corporations all target American technology for acquisition. When China illegally acquires technology from the United States, it free rides on the US's scientific investments and threatens its advantages in valuable commercial and military technology.

It is not clear the extent to which outright theft, versus legal technology acquisition and the cross-breeding of ideas and technology inherent in the globalization of science education and research, is driving China's technological rise. Nevertheless, the fact that the targets of Chinese acquisition are often those controlled technologies deemed crucial to American business and military dominance means the threat must be taken seriously.

US counterintelligence officials believe that China is the largest and most aggressive espionage threat in the world.[370] In terms of military technology, in just the last few years Chinese entities have been implicated in attempts to acquire protected space shuttle technology, missile technology, radar and electronic warfare technology, naval warship data, unmanned aerial vehicle technology, thermal imaging systems, and

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[370] U.S.-China Economic and Security Review Commission, "2009 Report to Congress," November 2009, p. 148.

military night vision systems, according to the Department of Justice.[371] Such technologies, as well as others desired by the Chinese military, are crucial elements in military systems that could challenge the military predominance of the United States.

Illicit acquisition of technology is also a threat to the technological engine of the American economy. Federal officials say that Chinese entities are among the most active in corporate espionage, and that these efforts are often directed against companies in Silicon Valley.[372] Technology companies Google, Cisco Systems, Motorola, Siemens and General Electric have voiced concerns or filed lawsuits over China's aggressive activities in trying to acquire their advanced technology, which undercut these companies' ability to secure ownership of their intellectual property.[373] Estimates of the cost of such activities to US businesses are difficult to obtain, particularly because American firms do not always come forward when their technology has been stolen, and the loss of intellectual property cannot be easily enumerated. A US Government report estimates that the combined cost of all foreign and domestic economic espionage in 2001 was $300 billion, a figure that has likely risen substantially since then.[374]

Theft of American technology is often conducted through the PRC's science and technology institutes and industrial enterprises. As described in the Department of Defense's 2010 report to congress on PRC military developments, and confirmed in a joint FBI/CIA report on China's intelligence activities, "the PRC utilizes a large, well-organized network of enterprises, defense factories and affiliated research institutes and computer network operations to facilitate the collection of sensitive information and export-controlled technology."[375] Ken Shiffer, who spent 29 years as a counterintelligence agent in the FBI, said that "the Chinese operations that I confronted or am familiar with all targeted specific technologies which were needed by specific institutes or organizations in China."[376]

In 2010, the Department of Justice (DOJ) prepared a brief on major enforcement and embargo prosecutions from January 2007 to June 2010.[377] Although the report is not exhaustive, China was involved in 27 out of 140 cases (19 percent), second to Iran. This is an indicator of China's extensive illicit technology acquisition activities and the degree of attention accorded the threat by US authorities. The prosecutions listed in these

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[371] Department of Justice, "Fact Sheet: Major U.S. Export Enforcement and Embargo Prosecutions (2007 to the Present), June 2010.
[372] John R. Wilke, "Two Silicon Valley Cases Raise Fears of Chinese Espionage," *The Wall Street Journal*, January 15, 2003. http://www.economicespionage.com/WSJ.htm
[373] Christopher Rhoads, "Motorola Claims Huawei Plot," *The Wall Street Journal*, July 22, 2010. http://online.wsj.com/article/SB10001424052748704684604575381362665259760.html?KEYWORDS=motorola+huawei
[374] Notra Trulock, "The High Cost of Espionage," *Accuracy in Media.* http://www.aim.org/media-monitor/the-high-cost-of-espionage/
[375] CIA FBI FOIA, 6. Office of the Secretary of Defense, Military and Security Developments Involving the People's Republic of China 2010. http://www.defense.gov/pubs/pdfs/2010_CMPR_Final.pdf
[376] Ken Schiffer, "Chinese Intelligence Collection Operations Against the United States," *Harvard Asia-Pacific Review*, Vol. 10, No. 1 (Spring 2009). This line is taken from an unpublished draft of the article.
[377] Department of Justice, "Fact Sheet: Major U.S. Export Enforcement and Embargo Prosecutions (2007 to the Present), June 2010.

documents reveal the involvement of Chinese R&D institutes in seeking to acquire US technology with potential military uses. For example,

- In 2009, three men were convicted for exporting sensitive carbon fiber material that can be used in aircraft, rockets and spacecraft. The customer was the China Academy of Space Technology, which oversees research institutes working on spacecraft systems for the government.

- William Chai-Wai Tsu exported more than 400 restricted integrated circuits with applications in military radars to China's "704 Research Institute." The Institute is affiliated with the state-owned China Aerospace Science and Technology Corporation.

- Qing Li was convicted of smuggling military-grade accelerometers that can be used in smart bombs and missile development to what her co-conspirator in China called a "special" scientific agency in China.

- Xiaodong Sheldon Meng pleaded guilty in 2007 to violating the Economic Espionage Act by intending to provide China's Navy Research Center with trade secrets regarding motion simulation for training purposes.[378]

- Dongfan "Greg" Chung, an aerospace engineer with the Boeing Company and Rockwell International, was convicted in 2009 of passing information on aircraft development to China for almost thirty years. At various times, he was tasked to collect technical information by the China National Aero Technology Import and Export Corporation, the Nan Chang Aircraft Company, and the China Aviation Industry Corporation.[379]

As these cases show, the Chinese military clearly benefits from stolen American technology, but in the Chinese S&T ecosystem, the line between government and private initiatives is blurred. US officials describe an "underground bazaar" of people trying to sell information to China, but no one knows the scope of these efforts or whether the government is soliciting the information.

State science institutions and the 863 program assist in military technology development, and as described by official US reports, have become entangled in instances of Chinese espionage. China's science funding programs can surely incentivize actors to steal secrets from foreign sources with military applications, both directly and indirectly. But in an environment in which the Chinese government increasingly relies on private sector entrepreneurs to develop important technologies, and in which both private and public funding can be tapped to spur the creation and commercialization of new technologies—whether stolen or independently developed—Chinese espionage cannot be

[378] Department of Justice, "Fact Sheet: Major U.S. Export Enforcement and Embargo Prosecutions (2007 to the Present), June 2010.
[379] U.S.-China Economic and Security Review Commission, "2009 Report to Congress," November 2009, p. 159.

pinned to any single science program. Rather, it is precisely the mixing of civilian and military programs, directed espionage and entrepreneurial espionage that represents a clear danger to expand the scope of technology theft in the United States, as the following cases illustrate:

- Lan Lee and Yuefei Ge, arrested for economic espionage in 2001 for attempting to steal microchip technology from their Silicon Valley employers, allegedly had entrepreneurial designs. Records show that the two engineers hoped to use technology stolen from Transmeta, Sun Microsystems and NEC Electronics to develop high speed microchips through a company located in Hangzhou that would manufacture them at low cost. A Beijing venture capital group was enlisted to bankroll the development of the chips. The goal of operation, according to the venture capital group, was profit. But American prosecutors also charged Lee and Ge with espionage when it became apparent that the investors sought additional funding through the 863 program and the General Armaments Department of the People's Liberation Army.[380]

- In July 2010, Motorola accused Huawei and twelve former Motorola employees of stealing trade secrets related to wireless communications. The lawsuit alleges that the defendants set up a rival company, Lemko, in 2002 while they were still employed at Motorola and stole trade secrets over the next five years, some of which they then passed to Huawei. The suit alleges that Huawei founder Ren Zhengfei began working with the defendants as early as 2001. The case was also tied to the PLA, with two employees of Lemko seeking to pass on Motorola's technology to an unnamed company that "contributed to the Chinese national defense and developed telecom technology and products for the Chinese military."[381]

In recent years, Chinese entities have also used cyber attacks to collect information from the US Government, defense industries, and corporations, often with the aim of collecting sensitive technological information. As described in a Northrop Grumman report to the USCC, China has carried out "a long term, persistent campaign to collect sensitive but unclassified information from US Government and US defense industry networks using computer network exploitation techniques."[382] These attacks have yielded at least 10 to 20 terabytes of data from US government networks, according to the report. One reported attack accessed materials on the US Joint Strike Fighter program (though

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[380] Ariana Eunjung Cha, "Even Spies Embrace China's Free Market," *The Washington Post*, February 15, 2008. http://www.washingtonpost.com/wp-dyn/content/article/2008/02/14/AR2008021403550.html
[381] Jamil Anderlini, "Motorola Claims Espionage in Huawei Lawsuit," *Financial Times*, July 22 2010. http://www.ft.com/cms/s/0/616d2b34-953d-11df-b2e1-00144feab49a.html
[382] Northrop Grumman, "Capability of the People's Republic of China to Conduct Cyber Warfare and Computer Network Exploitation" Prepared for The US-China Economic and Security Review Commission, October 9, 2009, p. 51. http://www.uscc.gov/researchpapers/2009/NorthropGrumman_PRC_Cyber_Paper_FINAL_Approved percent 20Report_16Oct2009.pdf

reportedly not its most sensitive information).[383] A massive computer attack against Google in 2010, and traced to Chinese hackers, reportedly involved theft of its proprietary computer code.[384]

US Government officials believe, said Northrop Grumman, that cyber-espionage "has the potential to erode the United States' long term position as a world leader in S&T innovation and competitiveness," and that "the collection of US defense engineering data has possibly saved the recipient of the information years of R&D and significant amounts of funding."[385]

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[383] Siobhan Gorman, August Cole and Yochi Dreazen, "Computer Spies Breach Fighter-Jet Project," The Wall Street Journal, April 21, 2009. http://online.wsj.com/article/SB124027491029837401.html

[384] Jessica E. Vascellaro, "Brin Drove Google to Pull Back in China," *The Wall Street Journal*, March 24, 2010. http://online.wsj.com/article/SB10001424052748704266504575141064259998090.html; Christopher Rhoads, "Motorola Claims Huawei Plot," *The Wall Street Journal*, July 22, 2010. http://online.wsj.com/article/SB10001424052748704684604575381362665259760.html?KEYWORDS=motorola+huawei#ixzz0yJWlZQ52

[385] Northrop Grumman, "Capability of the People's Republic of China to Conduct Cyber Warfare and Computer Network Exploitation" Prepared for The US-China Economic and Security Review Commission, October 9, 2009, p. 52.

Science, Technology and China's Military-Industrial Complex

China's defense innovation system has achieved startling progress over the last decade, producing high-tech systems and weapons faster than many foreign observers anticipated. This progress has been facilitated by reforms in the defense innovation system as well as efforts to tap into the benefits of the civilian high-tech economy and its integration in global R&D networks and production chains.

China's defense innovation system benefits from R&D in universities and industry supported by national science programs such as 863, and defense-specific programs such as the Basic Research Program. Joint-venture partnerships between academic-industry and industry-military entities promote the cross-pollination of technologies and aid in innovation. New government agencies such as the Civil-Military Integration Promotion Department (CMIPD) assist in setting common standards, facilitating exchanges, and disseminating knowledge among military and civilian organizations. New techniques and tools are introduced to the PLA through foreign participation in the development of dual-use technologies. Espionage is also an important factor in China's military rise, as described in the previous section.

The PLA's drive for technical modernization was jump-started by the impressive display of American power in the Persian Gulf War, as it caused China's military leadership to reexamine many of their fundamental strategic concepts. This set in motion a doctrinal shift from winning "People's War Under Modern Conditions"[386] to winning "Local War Under Modern, High-tech Conditions"[387] and in 2008, to winning "Local Wars Under Conditions of Informatization."[388] The new emphasis on information warfare generated new requirements for the service branches, military academics, and the defense industrial sector. In the last few years, China has been developing several high-tech solutions intended to disrupt and undermine the traditional advantages of the United States in warfare. China's anti-satellite missiles, its DongFeng-21D anti-ship ballistic missile (ASBM), and associated advanced sensors, seem intended to deny the American military access to the Western Pacific. New aerial drones are in development, and a newly-revealed prototype of a 5th generation fighter, the J-20, seeks to undo the US's near-monopoly on low-observable aircraft.

China's technological capabilities have grown at a remarkable rate given the obstacles it faced twenty years ago. China's defense industrial base in the early 1990s was ill-equipped to meet the demands of the PLA's new military imperatives. After decades of neglect and loss-making operations, much of the defense industrial sector was

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[386] Ellis Joffe, "'People's War Under Modern Conditions': A Doctrine for Modern War," *The China Quarterly*, No. 112 (December 1987), pp. 555-571.
[387] David Finkelstein, "China's National Military Strategy," in James C. Mulvenon and Andrew N.D. Yang, eds., *The People's Liberation Army in the Information Age* (Santa Monica, CA: RAND, 1999), pp. 127-128.
[388] Information Office of the State Council, "2008 China's National Defense White Paper," January 2009, http://www.chinamil.com.cn/site1/database/2009-01/21/content_1627265.htm

sapped of talent, competitiveness, and resources. Significant changes have taken place in the defense innovation system to address these problems.

In the 1990s, prioritizing the attainment of operational capability as quickly as possible, the PLA Navy and Air Force advocated for large-scale purchases of weapons systems from Russia, while COSTIND (the Commission of Science, Technology, and Industry for National Defense), the defense industry's supervisory agency, called for investments in China's own military-industrial base, with help from Russian scientists and technicians in particular gap areas.[389] COSTIND's views won over the State Council, which decided to undertake a far-reaching overhaul of the defense industrial complex, supplemented by the procurement of key systems from Russia, including in air defense and fighter jets.[390] Emerging from a long period of low investment in the defense industrial base, an effort to revitalize and reform the sector was underway.

Reforming the Military Technology Innovation Paradigm

Even with increased resourcing and closer leadership attention, reform of the defense industrial base has been an arduous task. The Chinese defense industrial base traces its roots to the military-industrial factories inherited from the Nationalist regime in 1949 and the subsequent Soviet technical assistance program. Since the reform era, the defense sector has evolved, but remains almost exclusively state-owned, with defense conglomerates and enterprise groups subordinate to the State Council. By the early 1990s the defense industrial sector encompassed 1,000 enterprises and more than two hundred major defense research institutes and engineering academies.[391]

Over the past 30 years, China's leadership has taken steps to rationalize and reform the bureaucracy overseeing the defense sector through a series of major reorganizations. In 1982, COSTIND was created out of an amalgamation of various other defense industry regulatory bodies, including the Defense Science and Technology Commission, the National Defense Industry Office, and the Science, Technology, and Equipment Commission. COSTIND reported to both the State Council, China's executive civilian authority, and the Central Military Commission (CMC), China's highest military body.[392] COSTIND oversaw the nation's conventional and strategic weapons programs and facilities, and served as the overarching regulatory body for the defense industries.[393] As the middleman between the defense industry and the end users—the PLA and the People's Armed Police—COSTIND was responsible for facilitating procurement processes and providing technical standards and regulations. Representing both procurer and producer created inherent conflicts of interest and led to constant bureaucratic infighting

[389] David Shambaugh, *Modernizing China's Military* (Berkeley and Los Angeles, CA: University of California Press, 2002), pp. 70-71.
[390] David Shambaugh, *Modernizing China's Military*, p. 71.
[391] David Shambaugh, *Modernizing China's Military*, p. 241.
[392] Nuclear Threat Initiative, "State Administration for Science, Technology and Industry for National Defense," December 2009, http://www.nti.org/db/china/costind.htm
[393] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy* (Ithaca: Cornell University Press, 2009), p. 49.

among groups representing different constituencies.[394] The result was an inefficient and stymied reform of military R&D processes, often leaving the services and political leaders frustrated.

In order to address the problems within COSTIND and the defense industry sector more broadly, the State Council in 1998 instituted a reorganization of the defense industry regulatory structure to split the civilian and military components of defense industry management between COSTIND and GAD. COSTIND was civilianized and placed under the State Council alone, while its military portfolio was largely transferred to a newly created PLA General Armaments Department (GAD), subordinate to the CMC.[395] COSTIND retained regulatory authority over the defense industries, export control authority of sensitive technologies, educational training of defense S&T personnel, defense conversion oversight, and management of foreign cooperation and acquisitions.[396] Part of the responsibility transferred to GAD was management of the military's research and development system, including management of the military portion of the 863 program.[397] This arrangement endured for a decade, until another restructuring in 2008.

The results of the 2008 restructuring are shown in Figure 17. It resulted in the creation of the Ministry of Industry and Information Technology (MIIT), one of five new "super ministries" approved by the National People's Congress. MIIT subsumed various other existing bureaucratic bodies or acquired parts of their portfolios, including COSTIND's.[398] Formerly a ministry-level body, COSTIND became a subsidiary agency of MIIT, and was renamed SASTIND (State Administration for Science, Technology, and Industry for National Defense). While SASTIND continues to be the civilian regulatory authority for the defense industry, it no longer enjoys bureaucratic parity with GAD. Now the primary customer of China's defense manufacturers, GAD plays several roles—as purchaser, regulator, and R&D partner. This means that military planners have gained greater clout in shaping the defense industry's evolution.

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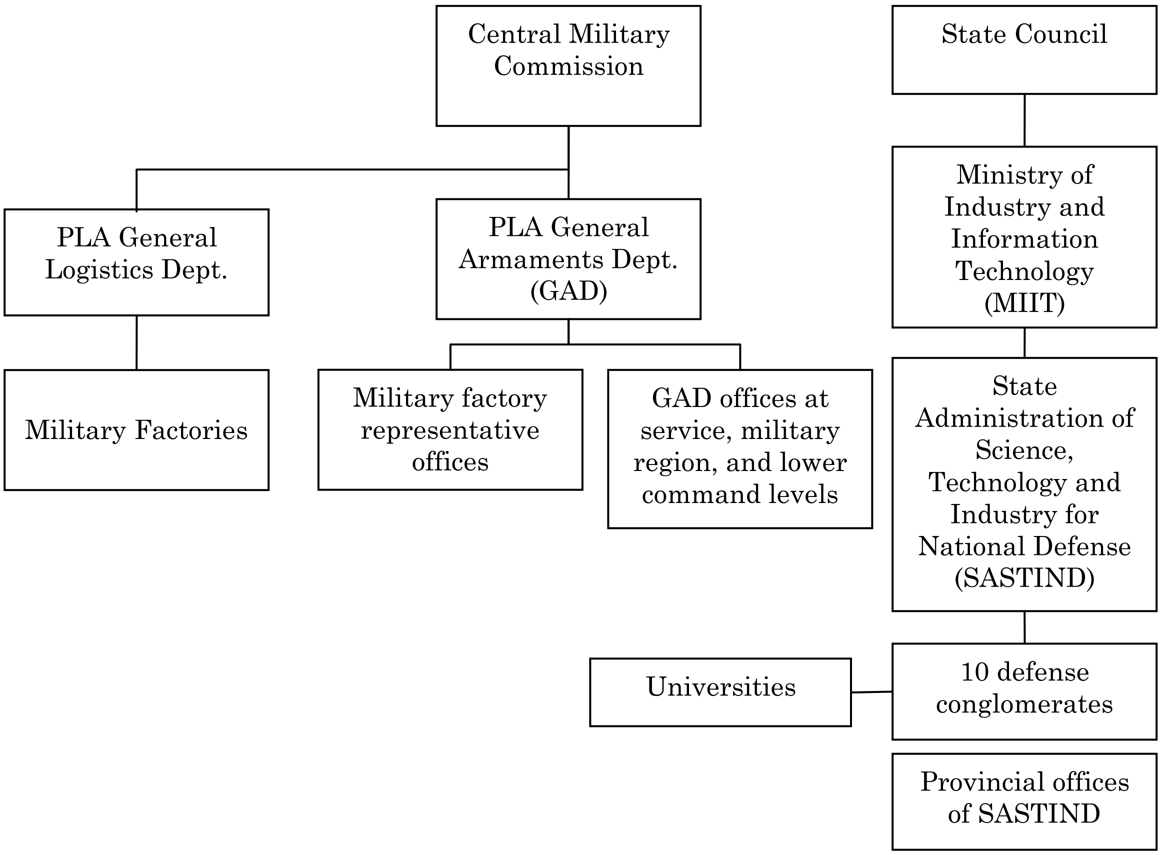
[394] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 112.
[395] The PLA as Organization, p. 274.
[396] It also gained control of the State Aerospace Bureau and State Nuclear Energy Administration, but several programs once under its purview—such as nuclear weapons development and the space launch program—were transferred to GAD.
[397] Ed Francis and Susan M. Puska, "Contemporary Chinese Defense Industry Reforms and Civil-Military Integration in Three Key Organizations," in Tai Ming Cheung, ed., *The Rise of the Chinese Defense Economy: Innovation Potential, Industrial Performance, and Regional Comparisons*, p. 32.
[398] "State Administration for Science, Technology and Industry for National Defense," Nuclear Threat Initiative, December 2009, http://www.nti.org/db/china/costind.htm (Accessed September 29, 2010) and Cheung, 116.

Figure 17: Chinese defense S&T organizational structure, 2008[399]



Concurrently with the 2008 bureaucratic reforms, the State Council established the Civil-Military Integration Promotion Department (CMIPD). While the department is directly subordinate to MIIT, it works in coordination with SASTIND to fulfill some of the dual-use tasks once assigned to COSTIND. These include proposing policies and regulations to promote dual-use technology development, overseeing the operations of the defense economy to promote civilian-military integration, promoting the sharing of resources between military and industrial partners, coordinating defense grant programs with promotion of intellectual property rights, and coordinating with other national agencies for foreign cooperation in space and nuclear activities.[400] One of the first major projects of CMIPD has been the formulation of common standards in industry and the military for shared products and technologies. Without such standards for processes, equipment, management and supervision, technology transfer is much more difficult.[401]

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[399] Adapted from Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 119.
[400] MIIT, "Department of Civilian-Military Integration Promotion," undated, http://jmjhs.miit.gov.cn/n11293472/n11295193/n11298538/index.html (Accessed September 29, 2010).
[401] Edward T. Francis, "Contemporary Chinese Defense Science, Technology and Industry Reforms, and Civil-Military Integration (CMI)," unpublished paper based on draft presented at the July 1-2, 2010

China's defense industry itself has also undergone extraordinary changes since the mid-1990s. Originally established as industrial ministries in 1950, over the course of four decades of bureaucratic and political turmoil, China's defense industries emerged in 1993 as five overarching defense manufacturing conglomerates, each supervising hundreds of subsidiary defense factories, shipyards, research institutes, and laboratories (See Figure 18).[402] In 1999, the State Council decided to introduce Western corporate structures and management concepts in order to provide "moderate competition" to the defense sector.[403] Each defense conglomerate was split into two organizations, one ostensibly catering to military customers and the other to the commercial market (See Figure 19). Combined with large-scale labor downsizing and plant closures, the intent of this policy was to create a nucleus of dedicated defense enterprises, served by a large external network of secondary suppliers and contractors.[404]

Figure 18: China's Defense Industries in 1993[405]

Ministry	Production Line
China National Nuclear Corp. (CNNC)	Nuclear power and nuclear weapons
Aviation Industries of China (AVIC)	All civilian and military aircraft
China Aerospace Corp. (CASC)	Space launch vehicles, satellites, missiles, and related equipment
China North Industries Corp. (NORINCO) and China Ordnance Industry Corporation (COIC)	Conventional weapons and ordnance
China State Shipbuilding Corp. (CSSC)	All commercial and naval shipping

Figure 19: China's Defense Industries in 2002[406]

Corporation/Conglomerate	Production Line
China National Nuclear Corp. (CNNC)	Nuclear weapons, uranium mining, and civilian nuclear power program operations
China Nuclear Engineering and Construction Corp. (CNECC)	Construction of nuclear power plants and defense infrastructure facilities
Aviation Industry Corp. of China One (AVIC 1)*	Advanced military aircraft, commercial aircraft, aero-engines, airborne weaponry, fire-control systems
Aviation Industry Corp. of China Two (AVIC 2)*	Medium sized aircraft, trainers, UAVs, and helicopters
China Aerospace Science and Technology Corp. (CASTC)	Space launch vehicles, satellites, and strategic and tactical missiles
China Aerospace Science and Industry Corp.	Missile systems, electronics, other ballistics

University of California, San Diego Institute on Global Conflict and Cooperation (IGCC) Conference on China's Defense and Dual-Use Science, Technology, and Industrial Base, Nov 2010, pp. 12-13.
[402] David Shambaugh, *Modernizing China's Military*, pp. 230-233.
[403] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 122.
[404] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 124.
[405] David Shambaugh, *Modernizing China's Military*, p. 233.
[406] Adapted from Shambaugh, 234 and Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, pp. 120-122.

(CASIC)	
China Ordnance Industrial Group Corp. (COIG)	Ordnance supplies, tanks, armored vehicles, machinery, chemicals, artillery
China Ordnance Equipment Group (COEG)	Miscellaneous ordnance, trucks, automobiles, motorcycles
China State Shipbuilding Corp. (CSSC)	Destroyers, frigates, submarines, missile corvettes, auxiliary space instrumentation, replenishment vessels
China Shipbuilding Industry Corp. (CSIC)	Frigates, destroyers, submarines, support craft, commercial vessels
China Electronics Technology Enterprise Corp. (CETC)	Defense electronics, communications, and other information technologies

*In 2008, Avic 1 and 2 merged

The central government also instituted policy measures to relieve some of the financial and social burdens that restrained growth for the defense industry. State banks were directed to provide low-cost and interest-free loans to defense corporations; divestment from social welfare entities, such as hospitals and schools, cleared up corporate balance sheets; and the establishment of a national social security system transferred some of the burden of laid-off and retired workers from enterprises to government balance sheets.[407]

A combination of corporate housecleaning and state support began to achieve the goals of streamlining the defense industry sector and cutting costs, allowing research spending to grow. China Ordnance Industry Group (COIG) and China Ordnance Equipment Group (COEG) had both been operating in the red for many years, but returned to profitability through restructuring in the early part of the last decade.[408] As a result, the defense industry conglomerates were able to plow their growing revenues back into R&D. COIG, for example invested RMB 600 million (USD 72.5 million) into technological development in 2003 and set a goal of spending at least 2 percent of annual sales revenue on R&D.[409]

Backed by government policies and statements of encouragement, the defense conglomerates were also acquiring or absorbing former government research institutes and laboratories, as a wave of corporatization swept through the national R&D system. Aviation Industries of China One (AVIC1), for instance, acquired 31 research institutes, AVIC2 acquired three, and the China State Shipbuilding Corporation (CSSC) took over 28 research institutes. The China Electronics Technology Enterprise Corporation (CETC) was newly created from various component IT and electronics companies in 2002, and as a consequence incorporated 47 electronics and IT research institutes in its founding.[410] The migration of civilian government research institutes into the corporatized defense industry system created new in-house R&D capabilities and, it was hoped, new spin-on and spin-off efficiencies.

[407] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 126.
[408] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 125.
[409] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 150.
[410] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 148.

While structural reforms to the defense industry and its relationship to regulators and customers were making headway, those reforms, in and of themselves, could not guarantee a congenial environment for S&T innovation. Rules governing R&D innovation and product quality were lacking. Defense researchers had little independent capability or incentive to pursue their own initiatives under the existing intellectual property protection regime.[411] In order to develop their ideas into marketable products, scientists and engineers needed the incentives and rent streams provided by intellectual property rights protections for their inventions. In the aviation sector, a 1999 *Science and Technology Daily* editorial summarized a system where design engineers, "bear the heavy burden of continually breaking new ground, but have nothing to do with the subsequent harvest," because ownership and subsequent revenues of the project were transferred to the production units once the designs were handed over.[412] Such disregard for intellectual property, the author opined, "[resulted] in the loss of a large number of talented people" and prevented the creation of a virtuous cycle of design and product development.[413] Successful R&D programs, such as in space and launch vehicles, were often driven by elite leadership attention and resources, rather than from bottom-up R&D innovation.

In 2004, the State Council and CMC issued a joint ordinance to reform the national defense patent system. The "National Defense Patents Ordinance" streamlined the process for filing defense patents and clarified how SASTIND and GAD would work together to approve patent applications from work units and individuals.[414] According to the deputy director of the new Defense Patent Office established under SASTIND, patent protections were needed to create an environment favorable for sustained cycles of innovation: "One-shot innovation is not difficult, what's difficult is continuous innovation…which requires protection of the inventor's rights and benefits."[415] The bureaucratic restructurings helped to rationalize work processes and reduce inefficiencies, but those reforms only laid the ground for innovative research. Reforms to intellectual property rights and the patent regime and increased funding from national research programs, led to a sharp growth in patent applications in the previous decade,[416] with some defense conglomerates proceeding apace in filing their own patents (See Figure 21).

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[411] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 147.
[412] Huang Qiang, "Will China's Aviation Industry Be Able to Get Out of the Doldrums Soon?" *Science and Technology Daily*, 8 July 1999, via Open Source Center: CPP19990811001697.
[413] Huang Qiang, "Will China's Aviation Industry Be Able to Get Out of the Doldrums Soon?"
[414] State Council and the Central Military Commission, "Defense Patents Ordinance," State Intellectual Property Office of the PRC, 17 September 2004, http://www.sipo.gov.cn/sipo2008/zcfg/flfg/zl/jsxzfg/200804/t20080403_369164.html (Accessed September 28, 2010) and Ministry of Defense, "Defense Patents Regulation," 13 July 2009, http://www.mod.gov.cn/policy/2009-07/13/content_3098769.htm (Accessed September 29, 2010).
[415] *Jiefangjun Bao*, "zongzhuang guofang zhuanliju fujuzhang yang jianbing tan jiaqiang guofang zhuanli gongzuo," (GAD Defense Patents Office Deputy Director Yang Jianbing Discusses Strengthening Defense Patent Work)," 20 June 2006, http://www.sipo.gov.cn/sipo2008/yw/2006/200804/t20080401_351693.html.
[416] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 110.

Figure 20: Defense conglomerates with the highest number of patents 2004[417]

Enterprise	Patent applications	Patents issued
China Ordnance Equipment Group	480	594
China Electronics Technology Corporation (CETC)	202	98
Aviation Industry Corporation of China One (AVIC 1)	180	132

Funding Priority Technologies

The process of reforming the defense industry and regulatory regime also provided an opportunity for China's leadership to enumerate and fund research priorities through the newly formed institutions. Levels of R&D funding for military purposes is not provided in official statistics, but may constitute 15 to 28 percent of national R&D expenditures, according to outside estimates.[418] SASTIND and GAD allocate funding not only to the defense industry and university system, but also to CAS and civilian universities to support R&D for weapons and equipment.

At least seven COSTIND/SASTIND funding vehicles have been identified through publication records:[419]

- National Defense Basic Research Program
- National Defense Science and Technology Advanced Research Fund
- National Defense Science and Technology Basic Program
- National Defense Science, Technology and Industry Civilian Use Conversion Research Program
- National Defense Science and Technology Key Laboratory Fund
- National Defense Model Type Program
- National Defense Fund

Since 1979, over 16,000 papers in a Chinese journal database cite these sources as their sponsors.

In addition, GAD supports research through at least two funds:[420]

[417] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 145.
[418] See *The Rise of the Chinese Defense Economy: Innovation Potential, Industrial Performance, and Regional Comparisons*, Tai Ming Cheung, ed., Study of Innovation and Technology in China (SITC), an IGCC Project, p. 11.
[419] Edward T. Francis, "Contemporary Chinese Defense Science, Technology and Industry Reforms, and Civil-Military Integration (CMI)," unpublished paper based on draft presented at the July 1-2, 2010 University of California, San Diego Institute on Global Conflict and Cooperation (IGCC) Conference on China's Defense and Dual-Use Science, Technology, and Industrial Base, Nov 2010, pp. 22-23.
[420] Edward T. Francis, "Contemporary Chinese Defense Science, Technology and Industry Reforms, and Civil-Military Integration (CMI)," unpublished paper based on draft presented at the July 1-2, 2010

- Weapons and Equipment Preliminary Research Fund
- Military Electronics Preliminary Research Fund

More than 400 papers since 1979 cite these programs as their research sponsor.[421]

Other national-level programs support research that is of a dual-use nature, including the 973 Program and the Torch program.[422] Perhaps most importantly, the 863 Program encompasses a wide range of scientific priorities, including a significant component of dual-use and military research areas. 863 priorities include, "laser technology, space, biotechnology, information technology, automation and manufacturing technology, energy, and advanced materials," of which COSTIND was given oversight of space and laser technologies, with MOST overseeing the remaining six areas. Within these broad areas, specific projects within the topics of, "space, laser, optoelectronics, super-large-scale integrated circuits, turbofan engines, and new materials," were targeted for funding as R&D fields with high applicability to dual-use or military applications.[423] As a result, these programs received a mix of civilian and military grant funding, creating opportunities for defense personnel to collaborate with civilian researchers (See Figure 21). During the 2001-2005 Tenth Five Year Plan the 863 Program may have received as much as 7 billion RMB ($845 million) for defense-related research, nearly one-third of total program funding.[424]

Figure 21: Dual-use nature of 863 program project funding (1986-2001)[425]

Category	Total number of projects	Number of projects with dual-use applications	Percentage of dual-use projects
Communications equipment	40	40	100 percent
Information electronic technology	8	8	100 percent
New materials products	63	60	97 percent
Electronics equipment	24	19	79 percent
Mechanical and electric equipment	35	28	77 percent

University of California, San Diego Institute on Global Conflict and Cooperation (IGCC) Conference on China's Defense and Dual-Use Science, Technology, and Industrial Base, Nov 2010, pp. 22-23.

[421] Edward T. Francis, "Contemporary Chinese Defense Science, Technology and Industry Reforms, and Civil-Military Integration (CMI)," unpublished paper based on draft presented at the July 1-2, 2010 University of California, San Diego Institute on Global Conflict and Cooperation (IGCC) Conference on China's Defense and Dual-Use Science, Technology, and Industrial Base, Nov 2010, pp. 22-23.

[422] "Message from the Director," Torch High Technology Industry Development Center, undated, www.ctp.gov.cn/ctp-eng/index.htm (Accessed September 29, 2010), and "Profile of 973 Program," Naational Basic Research Program of China, undated, http://www.973.gov.cn/English/Index.aspx (Accessed September 29, 2010).

[423] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 191.

[424] This number is not revealed in current official government statistics, but was suggested by Carl J. Dahlman and Jean-Eric Aubert, *China and the Knowledge Economy: Seizing the 21st Century*, joint publication of the World Bank East Asia and Pacific Region and the World Bank Institute, 2001, p. 128.

[425] Adapted from Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 192.

Projects that have received 863 funding that are linked to military modernization goals tend to be in areas where the military has identified needs and technological deficiencies. These include such areas as Command, Control, Communication, Computers, Intelligence Surveillance, Reconnaissance (C4ISR), aviation and aerospace, and information technology. Command and control systems are crucial for the PLA's operations, especially under "complex electromagnetic conditions." A typical example of the type of work supported by 863 funding includes a 2008 research paper published in *Firepower and Command and Control*. In it, the NUDT authors propose a method for, "modeling a C2 system in an information derivation based combat simulation system in a complex electromagnetic environment," creating a controlled environment for experimenting with tactics, techniques, and procedures for military operations.[426]

Another example of an 863 military project shows authors from PLA units and the Academy of Military Science collaborating on an improved air defense network for early warning, consisting of, "three levels of network systems," including a joint planning network for air defense preparations, a joint data network for target and firepower distribution, and a joint tracking network for air-defense and missile guidance and control.[427] The PLA unit from which one of the co-authors wrote was a missile brigade stationed in a coastal area of Fujian province near Quanzhou.

Finding Military Potential in the Civilian Sphere

The traditional isolation of state research institutions from the wider economy, referred to as the condition of, "*liang zhang pi,*" literally "two layers of skin" was also manifested in the defense sector's isolation from the civilian economy.[428] But reforms aimed at fostering civil-military integration (CMI) have been under way for a decade and the 2008 organizational reshuffling of the military innovation system have further encouraged the military to derive benefit from advances in the civilian innovation system.

The 2000-2005 Tenth Five Year Plan introduced a codification of this orientation under a set of four character principles including: "*junmin jiehe,*" or "integrating military and civilian needs," which calls for promoting technology spin-offs and spin-ons; and "*yujun yumin,*" or "finding military potential in the civilian sphere," an explicit call to develop a civilian dual-use technological and industrial complex.[429] President Hu Jintao subsequently encouraged "*junmin ronghe*," "civil-military fusion" and the 11th Five Year

[426] Gao Fugang, Zhao Ye, and Zhang Mingzhi, "Search on Modeling of C2 System in Combat Simulation System Under Complex Electromagnetism Environment," *Huoli Yu Zhihui Kongzhi*, July 2008, via OSC: CPP20100507465003.
[427] Geng Kui and Zhang Yandu, "Study on System and Functional Models of Air Defense Missile Network Operation Systems," *Huli yu Zhihui Kongzhi*, July 2008, via OSC: CPP20100702677020.
[428] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 106.
[429] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 182-183.

Plan has included reform initiatives to encourage the civilian economy to support China's military modernization.[430]

These guiding principles helped to formulate policy and the ongoing drive to break down barriers between the civilian and military R&D apparatuses, as well as state enterprises and commercial enterprises. These latest reforms to "fuse" civilian and military innovation are manifested in the structural reform of the defense innovation system described above. Reforms have also included attempts to strengthen civilian-military technology transfer facilities, build civil-military integration industrial zones, encourage civilian enterprise participation in weapons research and production, encourage civilian and foreign investment in the defense industry, and fund dual-use research programs.[431]

Academic research grants from programs like 863 and Defense Basic Research act as seed money for dual-use technology development; academic-industry joint ventures, supported by Torch funds, help commercialize these innovations; and government and military actors, like GAD, then act as final customer for the spin-off companies that their very funding programs may have helped nurture. Buoyed by these multiple lines and phases of S&T funding support, the civilian economy has emerged as a source of alternative procurement for the military, introducing greater competitiveness and innovation to defense enterprises, particularly in such products as electronics and information technology, where commercial products are near the state-of-the-art.

Civilian R&D Linkages

Growing defense expenditures and defense industry revenues have allowed defense enterprises to not only more effectively invest in their in-house R&D, but also to venture into the academic realm to find opportunities for cross-pollination with civilian researchers. For the 2006-2010 Eleventh Five Year Plan, the Chinese Academy of Sciences (CAS) issued a series of civilian research priorities for technologies that are inherently dual-use. CAS priority technology fields included research in nanodevices, fuel-cell engine technology, high-performance microchips, supercomputers, and servers. Defense enterprises increasingly reach out to universities to establish industry-university relationships and joint-venture partnerships. Several academic institutions have entered into cooperative agreements with defense enterprises. For instance, Tsinghua University and AVIC1 signed an agreement to train industry personnel and cooperate in certain R&D projects. Hunan University also entered into a cooperative relationship with defense enterprise Jiangnan Machinery Group to conduct military and dual-use R&D in automobile engineering, electric automation, and chemical engineering.[432]

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[430] Edward T. Francis, "Contemporary Chinese Defense Science, Technology and Industry Reforms, and Civil-Military Integration (CMI)," unpublished paper based on draft presented at the July 1-2, 2010 University of California, San Diego Institute on Global Conflict and Cooperation (IGCC) Conference on China's Defense and Dual-Use Science, Technology, and Industrial Base, Nov 2010, pp. 1, 5-6.
[431] Edward T. Francis, "Contemporary Chinese Defense Science, Technology and Industry Reforms, and Civil-Military Integration (CMI)," November 2010, pp. 5-6.
[432] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 208-9.

SASTIND has also led initiatives to establish joint R&D laboratories with leading universities focused on strategic, dual-use high-technology projects, and systems integration technologies throughout the country. Many of the technicians and researchers channeled into these laboratories are likely recruited from SASTIND and the partnered civilian universities, given that SASTIND helps to arrange job assignments for one-third of all graduates from its universities within the defense economy.

On the military side, GAD maintains linkages with local universities through the military representative office (MRO) system. For example, GAD's Xi'an Military Representative Bureau established cooperative ties with more than 360 R&D institutes in eighteen provinces, and employs special ad hoc technical work teams drawn from across the defense industry.[433]

The ongoing establishment of "key research facilities" in defense industry and civilian institutions supports the exchange of civilian and military talent and technology. National Defense Key Laboratories have been around since the 1990s, but they appear to be increasing in number and variety as they receive increased funding under the 11th Five Year Plan. Managed by SASTIND and reviewed by GAD, National Defense Key Laboratories come in different arrangements, as described by a former COSTIND director. National Defense Science and Technology State Key Laboratories are comprehensive laboratories and conduct basic defense research, research on strategic high technology and systems integration. National Defense Science and Technology Key Laboratories are specialized laboratories for exploratory and crux technologies. National Defense Key Academic Branch Laboratories engage in research to help field capabilities involving new principles and methods. These labs can be located in defense industries, defense universities and civilian universities. For example, the State Key Laboratory of Deep Buried Target Damage was established in the civilian North University of China. Since 2003, COSTIND and SASTIND have also approved 20 Defense Science, Technology and Industry Advanced Technology Research and Application Centers, established jointly by multiple defense, university and research organizations to turn basic research into engineering achievements.[434]

Civilian Industry Linkages

The steady growth in China's defense budget has created a market incentive for private firms to cater to military priorities. In a 2005 survey, a GAD researcher found from a sample of more than one hundred civilian high-tech firms, research institutes, and university faculties across six regions of the country that "more than 90 percent of firms…were keen to enter the military market" and "more then 90 percent of IT enterprises…indicated that they had already established ties with the military, and some were already selling their products to the PLA."[435]

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[433] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, pp. 153, 166, fn. 213.
[434] Edward T. Francis, "Contemporary Chinese Defense Science, Technology and Industry Reforms, and Civil-Military Integration (CMI)," Nov 2010, pp. 13-17.
[435] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 214.

Initiatives on Civil-Military Integration Industrial Bases and Civil-Military Integration Industry Zones in recent years were designed to create more sustainable linkages between defense and civilian enterprises. Since 2008, new base programs have included Hubei's Xiangfan Aviation and Aerospace Industry Zone, the Zhuhai Aviation Industry Zone and the Guangyuan City Tashantai Civil-Military Integration Industry Zone, designed to become a research and production base for electronics systems and equipment.

Even though China's defense procurement comes almost exclusively from state enterprises, efforts have been made to increase civilian participation and investment in defense production. Civilian involvement was encouraged by a 2005 State Council opinion on developing the non state-owned sector and by the State Council's 2007 "Approval of a Few Opinion Regarding Deepening National Defense Science Technology and Industry Investment System Reforms," which then led to rules being clarified to liberalize civilian and foreign investment in defense industry enterprises. However, the changes to date have not been that dramatic. Civilian enterprises still have trouble receiving approvals to build weapons and have difficulty competing against incentives and tax breaks given to defense industries.[436]

Grooming Talent

The increasing integration of civilian and military spheres has been reflected in investments in human capital, through education and college recruitments. Combined with civilian educational policies, such as Project 211 —a national program to create 100 world class universities in the 21st century—the number of college graduates in the military and defense industry has grown steadily. For instance, of the 284,000 students who graduated from SASTIND-administered universities between 1999 and 2005, 18 percent went to work in the defense economy, 35 percent of whom had advanced degrees.[437]

As China's university system has improved, the defense economy has drawn an increasing number of high caliber engineers, technicians, and scientists into defense enterprises. Similarly in the military, the National Defense Students Program has targeted civilian college graduates for fast track officer training and accession into the PLA. The program has grown steadily from a handful of participating universities to 116 in 2007.[438] College graduates recruited through this program are cited as adding highly sought after technical expertise, more creative thinking, and comfort with information technology into the PLA. The "511 project" is another program targeting the improvement of defense human capital. The goals of the program are to raise the educational level of

[436] Edward T. Francis, "Contemporary Chinese Defense Science, Technology and Industry Reforms, and Civil-Military Integration (CMI)," Nov 2010, pp. 18-21.
[437] Tai Ming Cheung, "The Chinese Defense Economy's Long March from Imitation to Innovation," in Tai Ming Cheung, ed., *The Rise of the Chinese Defense Economy: Innovation Potential, Industrial Performance, and Regional Comparisons*, 22.
[438] John F. Corbett, et al., "Building the Fighting Strength: PLA Officer Accession, Education, Training, and Utilization," in Roy Kamphausen, et al., eds., *The People in the PLA*, (Carlisle, PA: Strategic Studies Institute, September 2008), pp. 147-153.

key personnel within the defense industry by the "grooming of five hundred senior management-level cadres, one thousand technological team leaders, and ten thousand high-quality technical specialists."[439] The net effect of these programs and policies has been to leverage improvements in recent years in China's academic sphere and apply them to the defense industrial and military spheres.

Examples of Civil-Military Collaborative Projects

The proliferation of linkages among civilian, military and defense industry research institutions has created a complex network of cooperation. The impacts of Chinese S&T promotion policies can be witnessed in the multitude of joint civil-military projects and products that have been developed across multiple technology sectors. One of the most prominent successes of civil-military collaboration has been in information technology. China's first indigenous core network router was developed through a civil-commercial-military collaboration using 863 funds and "touted as a critical breakthrough for the country's commercial and military information infrastructure by providing high-speed network switching…and improved security mechanisms."[440] Under the auspices of CAS and CAE, the National University of Defense Technology (NUDT) partnered with Datang Telecom Technology in the development of the *Yinhe Yuheng* core router, funded by 863 grants.[441]

Civil-military collaboration is also demonstrated in the field of supercomputers, where China has been developing indigenous technology, in part because of US export controls. Dawning, a maker of Chinese supercomputers, expects to be able to use a Chinese-developed processor in its supercomputer in 2011, the latest version of the Loongson ("dragon core"), being developed by CAS's Institute of Computing Technology (ICT) to replace some US-designed chips. This success is part of a larger government effort to use supercomputing centers (there are 10 facilities nationwide) to encourage the development of local semiconductor technology. These computers are typically used by the PLA in weapons research and are thus too important to trust to foreign vendors, according to Michael Clendenin, managing director of RedTech Advisors.[442]

As a national center of excellence in supercomputing and network technologies, NUDT has spun-off commercial concerns that provide products and services to the government and military. Hunan Heamam System Co., for example, is one such spinoff company. The company collaborates with NUDT's Information Security Joint Laboratory to develop network security products such as firewalls, intrusion detection systems, and scanning software. Products such as its line of "Tianyi Galaxy firewalls" receive National Torch Program funding and are sold to government agencies nationwide.[443] While not

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[439] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 156, fn. 189.
[440] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 221.
[441] Li Wen and Wang Wowen, "Birth of China's First Core Router," *Jiefangjun Bao*, 7 May 2001, p. 2.
[442] Bruce Einhorn, "China: Dawning's Plans for its Loongson Chips," *Bloomberg Businessweek*, June 17, 2010; Clay Dillow, "China's Loongson Processor Could Power First Natural-Born Chinese Supercomputer," *Popular Science*, January 2010.
[443] Hunan Heamam System "Company Introduction." http://www.ty666.com/jt.asp?id='%B9%AB%CB%BE%BC%F2%BD%E9'

trumpeted by the company, Hunan Heamam appears to have direct links with the PLA's GAD. The GAD Director of the Department of Original Investments, Senior Colonel Ding Feng, paid an inspection visit to the company in 2005.[444] The example of Hunan Heaman exemplifies the prominent role that national research programs play in developing a more robust S&T base.

Foreign Linkages

Being able to harness the benefits of dual-use technologies has meant that the PLA's defense innovation system also benefits from links between Chinese and Western firms. Dual use technologies desired by China, says the US Department of Defense, include electronics and semiconductor components, telecommunications products, high-grade numerically-controlled machine tools, aircraft, and spaceflight systems. In many of these areas, US and other Western multinational firms work to develop new technologies and products with Chinese companies that may appear removed from the defense sector, but, in fact, maintain deep ties with the PLA. The PLA serves, for many of these firms, as a funding source, research partner, or customer.[445]

US International Traffic in Arms Regulations (ITAR) prevent the export of defense technologies on the US Munitions List from being shared with foreign entities without approval. US export controls on dual-use technology also restrict the export by US firms of commercial-use technologies that could enhance China's military capability if incorporated into weapons systems.[446] Companies of European and other advanced industrial economies are subject to their own government controls. Yet, shaping export control policies to both preserve US competitiveness—and the billions of dollars of business conducted with Chinese firms—and prevent the transfer of sensitive technologies remains a difficult balancing act.

Links between Western and Chinese firms in dual-use areas include collaborative R&D activities, joint ventures and other strategic partnerships. Multinational IT and electronics firms, moreover, have transferred core technologies as a means to obtain market share.[447] Western firms, as described earlier, also provide intangible knowledge flows and training in advanced methods of research and management.

China's military shipbuilding industry is one area that has benefited greatly from the cross-pollination of civilian and military R&D, along with close integration in the global marketplace. Technological innovations derived from civilian shipbuilding are

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[444] Hunan Heamam System "Growth Process."
<http://www.ty666.com/jt.asp?id='%B9%AB%CB%BE%BC%F2%BD%E9'

[445] James Mulvenon and Rebecca Samm Tyroler-Cooper, "China's Defense Industry on the Path of Reform," paper prepared for the US-China Economic and Security Review Commission, October 2009, p. 38

[446] Bureau of Industry and Security, Department of Commerce, "Press Release on the China Rule." http://www.bis.doc.gov/news/2007/06-15-07-export-rule-press-release---final.pdf

[447] James Mulvenon and Rebecca Samm Tyroler-Cooper, "China's Defense Industry on the Path of Reform," p. 38-9.

easily transferred to military production since many processes and techniques are shared in both civilian and military contexts, such as computer-aided design and modeling. The transfer of management know-how and technical expertise has resulted in material benefit for both commercial and military shipbuilding in China.

China's major shipyards in Dalian, Jiangnan, Hudong, Guangzhou, Shanghai, and Bohai have all entered into foreign partnerships in which firms from Japan, Germany, South Korea and elsewhere that have transferred "advanced production technologies, including computer-aided manufacturing and management systems, hull construction integration systems, processing and testing equipment, high-efficiency processing facilities, and other technologies through purchase, licensing, and consignment."[448] Japanese companies heavily invested in Chinese shipbuilding include Mitsubishi Heavy Industries, Kawasaki Heavy Industries, IHI Heavy Industries, Sumitomo Heavy Industries, and Hitachi Zosen. Many have engaged in multi-year technology transfer agreements, such as those between Jiangnan Shipyard and Mitsubishi.[449] Chinese institutes and factories have also coproduced marine engines and equipment based on original designs by firms from Germany, Denmark, Switzerland, Austria, Norway, and elsewhere.[450]

As China looks to improve its military aviation sector—long considered a laggard in the Chinese defense sector—it will use international collaboration on dual-use components to try to overcome technical obstacles. China's aircraft are largely derived from Soviet and Russian systems. China acquired the Sukhoi SU-27 fighter jet from Russia and inked a 1996 licensing agreement for assembly and production of the jets, which gave the domestic aviation industry access to third-generation technology.[451] Despite China finding ways to copy and re-innovate these systems, the aviation sector still has problems with systems and quality control.

Yet China's recently revealed J-20 prototype, a fighter plane with stealth characteristics, could benefit from the spin-on benefits of dual-use technology that are being developed with help from Western suppliers. China's development of the single-aisle civil airliner C919 is one major project involving multiple multinational suppliers, from whom Chinese companies will learn advanced production tooling and manufacturing processes. Some of the Chinese companies producing subsystems with multinationals will be able to apply their know-how to the J-20 and other military models. Despite both government and corporate technology transfer restrictions and intellectual property guarantees, China's experience working with General Electric and the German firm MTU in producing propulsion units for the C919 could help serve the development of more

[448] Evan S. Medeiros, Roger Cliff, Keith Crane, James C. Mulvenon, *A New Direction For China's Defense Industry*, (RAND Corporation, 2005), p. 141.
[449] Evan S. Medeiros, Roger Cliff, Keith Crane, James C. Mulvenon, *A New Direction For China's Defense Industry*, pp. 131-2.
[450] Evan S. Medeiros, Roger Cliff, Keith Crane, James C. Mulvenon, *A New Direction For China's Defense Industry*, 141.
[451] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 139.

reliable military jet engines.[452] AVIC subsidiaries, such as Xi'an Aero-engine PLC, also have joint ventures with engine manufacturers Pratt & Whitney, Rolls Royce and Balcke Durr.[453]

In electronics and ICT, China boasts increasingly sophisticated products—for missiles, radars, avionics, electronic warfare, passive detection and electronic support measures (ESM) and battlefield communications. Most are developed by defense electronics firms belonging to the state defense conglomerate CETC. In some instances, its products are approaching the technological levels of the US and Europe and are economically priced. International cooperation in electronics was largely conducted with Russia since the 1990s, when the Chinese sent their engineers into Russian firms to study how the technologies were produced. US and European firms are limited in their sales of many military-use electronics components to China due to arms embargoes, although one Western company—a Norwegian electronics manufacturer, Sensonor— does offer products based on Micro-Electro-Mechanical Systems (MEMS) technology that it says is not restricted by ITAR rules. These products could allow Chinese missiles and guided weapons to achieve levels of accuracy similar to their Western counterparts.[454]

China sill benefits from Western collaboration in other dual-use areas of ICT. Technology and knowledge flows have come from R&D collaborations that are typical of the globalized technology environment has led to Western companies to form links with Chinese research entities that have both civilian and military functions. For example, telecom companies have transferred technology to, and have joint R&D programs with, the Beijing University of Posts and Telecommunications (BUPT), an institution that is involved in cybersecurity and has links to the PLA.[455]

Another example of firms with substantial global linkages, but ties to the PLA, are China's powerhouse telecommunication companies Huawei and ZTE. The PLA and SASTIND are believed to have provided substantial R&D funding to Huawei to develop tailored products for military use.[456] ZTE, for example, supplies high-side and trunk-line optical network systems to the PLA.[457] Yet these firms are also integrated into a global R&D fabric and have benefited from foreign collaboration throughout their rise. Included among Huawei's international links are Texas Instruments, which in 1997 set up laboratories to help Huawei train engineers and develop digital signal processing technologies, and Motorola, which set up a joint lab with Huawei in the same year to develop high-speed switching and routing equipment ideal for an air defense network.[458]

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[452] Feng, "My Thoughts on J-20," weblog post, Information Dissemination, January 2, 2011. http://www.informationdissemination.net/2011/01/my-thoughts-on-j-20.html/
[453] James Mulvenon and Rebecca Samm Tyroler-Cooper, "China's Defense Industry on the Path of Reform," p. 54
[454] Rafael Smith, "Report from the 2010 Chinese Defense Electronics Exhibition (CIDEX): Growing Industry – Advancing Technology," International Assessment and Strategy Center, October 3, 2010. http://www.strategycenter.net/research/pubID.230/pub_detail.asp
[455] Based on authors' analysis of and joint authorship in papers in Chinese technical journals
[456] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 216.
[457] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 219.
[458] Gary Milhollin, "Testimony of Gary Milhollin: Before the U.S.-China Security Review Commission October 12, 2001," http://www.uscc.gov/textonly/transcriptstx/tesmil.htm (accessed May 7, 2010).

Joint ventures with foreign partners have also allowed ZTE to work with Motorola and Texas Instruments in R&D activities.[459]

Defense innovation systems across the globe are evolving to incorporate civilian technologies necessary for creating the most modern defense systems. China still has a long way to go to become more agile in building systems utilizing the best of defense-industry discoveries and commercial technologies. Nevertheless, even at this early stage, China has profited greatly from the churn of technology in its own national innovation sector and in the global R&D networks in which China partakes. Going forward, the improvement in China's innovation capacity in the civilian sphere will no doubt translate into improved capabilities for the PLA.

[459] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, p. 220.

Conclusion: China as a Rising Power in Science and Technology

China's attempt to build scientific and technological capabilities is a national project that has endured from imperial times, through the Republican era and Mao years, into the present. While the project has endured, it has been interrupted by periods of war and political strife, and has lacked a stable formulation for linking scientific and technological advances to overall societal modernization. The past 30 years of relative political stability, however, have constituted a unique period in China's modern history, providing opportunities for scientific and technological development unprecedented in the past 150 years.

Complex dynamics surround China's scientific and technological development. By many measures, China is on its way to becoming a major power in science and technology. The rapid increase in its spending, the rise in international publications and surge in patent grants all point to growing capabilities. China's S&T workforce is among the largest in the world and it is building modern facilities at a remarkable rate. China has demonstrated the ability to take on complex science and engineering projects in a variety of areas and seeks to develop scientific and technological capabilities across the board, an aspiration characteristic of global science and technology powers. Its scientific and technological development plans enjoy robust elite support in ways that few other countries do.

At the same time, Chinese and foreign observers have raised many questions about the current performance of the Chinese systems for research and innovation and the prospects for their furthering scientific and technological development. While China is spending an increasing amount of money on innovation, it may not be getting an adequate return in the quality of research outputs, or the pace and originality of its innovations. These problems of performance can be traced back to the institutional arrangements for supporting science and technology, misconduct and corruption that stem from these, difficulties of recruiting and training world-class scientists and engineers, and weaknesses in the educational system. Many of these problems are not easily corrected, but are related to larger governance arrangements for research and innovation in China. Bureaucratic rivalries compromise program effectiveness, the role of the Ministry of Science and Technology has become a subject of considerable controversy, and serious disconnects between policy, programs and budgets are apparent. The persistence and deep-rootedness of these problems have tended to produce "half-full-half-empty" assessments of the prospects for China's rise as a science and technology power.

This report has attempted to push the analysis in several new directions in order to go beyond the "half-full-half-empty" conclusion, starting with a discussion of China's increasingly well-funded national government R&D programs. While central government funding still accounts for the bulk of the spending for these programs, it is increasingly being augmented by the spending of local governments, Chinese companies, bank loans, and tax incentives. The MOST-sponsored national R&D programs, while disappointing to many, have contributed to China's technological development in a variety of fields and have helped promote China's emergence as an important contributor to the world's scientific literature. But, as noted above, these programs account only for about 20 percent of the government's R&D effort. The rapid rise in the budgets of the NSFC and the Chinese Academy of Sciences under the "Knowledge Innovation Program" must also be considered in assessing government R&D programs. In addition, with the initiation of the megaprojects under the MLP, a number of other ministries have also become major supporters of national R&D, including the National Development and Reform Commission, with its key role in supporting high-technology industrialization. While it is difficult to assess the cost-effectiveness of China's many national R&D programs, they have certainly aided the progress of Chinese scientific research.

That progress would be inconceivable, however, without international cooperation. Such cooperation includes the enabling linkages to foreign universities, which have trained hundreds of thousands of Chinese students in science and engineering since the 1980s; foreign governments, with whom China has a host of science and technology agreements; and foreign companies who have transferred vast amounts of technology to China and are increasingly developing technology in China through the establishment of R&D centers. China's scientific and technological development also enjoys broad support from the diaspora of talented Chinese scientists and engineers in the United States and elsewhere.

The existence of China's government-sponsored national programs supports the image of a state-centric scientific research and high-technology effort. While this image is correct, it needs careful qualification. For one, China is by no means unique in embracing an active role for the state in promoting science and technology. Many other countries do this, including the United States, where the government plays a critical role in pushing the nation's science and technology base forward in support of economic competitiveness and national security. China has studied the US experience seriously, as well as the scientific and technological development strategies of Europe, Japan, and South Korea, and has attempted to incorporate best practices into strategies that fit Chinese conditions. A critical question is whether China is being consistent with its international commitments in doing so.

Focusing solely on the activities of the central government will produce a distorted picture of what has become a far more complex and differentiated national innovation system. First, over the past decade, the role of provincial and sub-provincial governments has become far more important, with local authorities now supporting almost as much spending on science as the central government. Many local governments enjoy substantial financial resources and local officials are incentivized by the national government to support research and innovation. As a result, local governments have crafted their own industrial policies to support the development of high-technology industries, and have become important partners with national level institutions in establishing new platforms for R&D, technology diffusion, standards development, and high technology industrialization. Since most Chinese provinces are larger than most countries, the successful establishment of provincial-level innovation systems means that in additive terms, the Chinese *national* system begins to take on a sui generis quality, the likes of which the world has never seen.

Second, while there is no doubt that the legacy of central research planning and national mobilization to support technological development in the "two bombs, one satellite" (*liangdan yixing)* tradition continues to have a hold on many members of the national technical and political communities, the China of today is quite different in terms of the power of market forces and in terms of the diversity of the industrial economy. Chinese enterprises face domestic and international market competition that incentivizes technological upgrading. Many of them have been the beneficiaries of significant central and local government policy support for innovation. It is therefore not surprising that the enterprise sector of the R&D system has become the largest in terms of financial commitments and the performance of R&D.

The simple fact that the business enterprise sector now accounts for roughly 70 percent of the national R&D effort should not obscure the fact that there is considerable diversity among Chinese companies in their approaches to innovation. These range from *shanzhai* ("mountain village") firms in the Shenzhen area that modify existing international products in creative ways to meet Chinese market preferences, to dynamic high-technology firms in places like Jiangsu province and Beijing's Zhongguancun district, where Chinese scientists and engineers returning with knowledge acquired abroad, take advantage of local policy incentives to establish innovative firms. Large state owned enterprises with well-established R&D laboratories, are also part of the mix, as are spin-off companies from research institutes and universities. Many of these enterprises are parts of global production chains involving complex international technology flows. This considerable economic diversity makes generalizations about the Chinese enterprise sector quite difficult, and it also induces caution in generalizing about the role of the state.

Nevertheless, this report has explored the Chinese government's efforts to marry its national R&D programs with major industrial development programs, with particular reference to the megaprojects. It is by no means clear that these projects are a sensible use of money; they have been plagued by management problems, and whether they will lead to the desired technological "leapfrogging" into a competitive position for China's high-technology products remains to be seen.

It is also clear that China still relies heavily on foreign technology for its innovation projects, and that inducing foreign companies to cooperate in them and share technology is an important part of these efforts. The significance of this foreign technology, though, would be much diminished without the important reforms and restructuring that have occurred in both civilian and military industry and China's ongoing technology development programs. Whereas the critical task of assimilating and absorbing foreign technology was often neglected in the past, this is no longer the case, with the result that China is in a position to capture technological capabilities from technology-intensive foreign investment in ways it formerly could not. While it is highly unlikely that China's national science programs by themselves could sustain the kinds of leapfrogging in capabilities under way in both military technology and in the kinds of industries targeted in the megaprojects, those programs have created increasingly capable human and institutional resources for assimilating, reengineering, and deploying the best technology that China can acquire from the international system. When combined with the "China price," huge domestic market, and an aggressive export promotion strategy, China has the makings of a formidable innovation system.

While the Chinese model of science has proven to be remarkably effective for technological "catch-up," it remains to be seen how effective it will be in the future. The case study of the nanotechnology field offers some insights into problems and prospects of Chinese efforts in cutting-edge areas of science. There is recognition in Chinese science policy circles that China will remain in the position of a follower in many of today's established high-technology industries. On the other hand, observers expect China will be poised to take an increasingly prominent leadership position in new areas of S&T outlined in China's technology foresight documents over the course of the coming decade.[460] China's strong showing in areas of nanotechnology and clean energy technologies may be early indications of this trend.

On the other hand, there are good reasons to think that the Chinese model for science in its current form is unlikely to deliver on the aspirations held for it. First, should the Chinese model drift further in a techno-nationalist direction, which some Chinese and foreign observers now perceive, it risks compromising the enabling international linkages that have been so important in the past, and are likely to become even more important as cutting-edge research and innovation become more globalized. Second, in spite of the robust efforts being made to stimulate innovation in Chinese enterprises, it is clear that an effective ecosystem for industrial innovation has yet to appear, and is unlikely to in the face of a weak culture of intellectual property protection, financial institutions that bias investments towards politically privileged corporations, and ill-advised, bureaucratically developed industrial policies that seek to pick winning industries and winning products. Third, the operation of the research system under the current Chinese model is unlikely to generate the truly creative research on which future high-technology leadership will depend. The level of basic research remains low but, more importantly, too much of the nation's research effort is being driven by bureaucratically-set objectives and bureaucratically-determined success criteria.

One of the consequences of China's five-year planning cycles is that it forces consideration of how R&D activities fit in with larger economic and national development objectives. The planning process also creates incentives for the major science agencies to strategize about programs they would like to promote in order to expand their access to budgetary resources. As it has operated in recent budget cycles, the planning process introduces regular churn into Chinese public policy, and this seems to be true of the new 12th Five Year Plan, as its outlines become clear.

While we can certainly expect continuities from the 11th Five Year Plan, some of the new directions that can be anticipated from the 12th are likely to be quite important and will have significant implications for Chinese research and innovation. This is particularly true for the growing importance of energy, the environment, health and welfare, urbanization and overall social development. While the Chinese economy is likely

[460] See, for instance, Chinese Academy of Sciences, *The Science & Technology Revolution and China's Modernization.* Supra, footnote 8.

to remain strongly export driven, the 12th Five Year Plan will focus far more attention on domestic consumption and meeting the social development needs of the country. The seven areas of industrial development identified as "strategic emerging industries" in the October 10, 2010 State Council Decision, noted above, have the quality of "grand challenges" that are intended to address pressing national problems, advance the nation's knowledge base, and stimulate the creation of internationally competitive firms in emerging industries.[461] Unlike the more techno-nationalist themes associated with the indigenous innovation policies of the 11th Plan period, the language of the 12th Plan will likely be far more techno-globalist in tone, with an acknowledgment of the importance of international S&T cooperation and with new opportunities for foreign companies to participate in national R&D programs with Chinese partners.[462] Aggressive industrial policy measures may persist, but they are more likely to conform to the norms of the international market system than we have seen in the recent past.

In short, China will be embarking on its 12th Plan with a mixture of anxiety over the domestic problems it faces, concern over how its rise is being perceived internationally, and confidence that it has an increasingly capable system of research and innovation and a toolkit for industrial policy that has been tested and adjusted through trial and error. In spite of the many problems that continue to trouble China's innovation system, there is little doubt that important advances in Chinese science and technology will attract increasing international attention and make China an increasingly attractive partner in research and innovation. In trying to find the balance between market forces and state directed innovation, and between domestic technological development and employment of foreign technology, China has not always gotten it right. Nevertheless, there is a clear sense of vision about the importance of science and technology for China's future, a clear commitment by the political elite to that vision, and a willingness to make resources available for the facilities and people needed to realize it. It is this vision and commitment that capture the imagination of the foreign observer as China enters the second decade of the 21st century. The China that emerges from the pursuit of the vision, in spite of the manifest obstacles to its realization, will be a formidable presence in the realms of economy and security.

[461] Cf., US National Academy of Engineering, "Grand Challenges for Engineering." http://www.engineeringchallenges.org/cms/challenges.aspx.
[462] State Council, "Guowuyuan Guanyu Jiakuai Peiyu he Fazhan Zhanluexing Xinxing Chanye de Jueding" (Decision to Accelerate the Development of Strategic Emerging Industries) October 10, 2010, Guofa [2010] No. 32. http://www.gov.cn/zwgk/2010-10/18/content_1724848.htm

Appendix I: CAS Institutes

The 100 Institutes of the Chinese Academy of Science[463]

Basic Research
Academy of Mathematics and Systems Science
Fujian Institute of Research on the Structure of Matter
Hefei Institutes of Physical Sciences
Institute of Chemistry
Institute of High Energy Physics
Institute of Mechanics
Institute of Modern Physics
Institute of Physics
Institute of Theoretical Physics
Nanjing Institute of Astronomical Optics & Technology
National Astronomical Observatories
National Center for Nano Science and Technology of China
National Time Service Center
Purple Mountain Observatory
Shanghai Astronomical Observatory
Shanghai Institute of Applied Physics
Technical Institute of Physics and Chemistry
Wuhan Institute of Physics and Mathematics

Life Sciences and Biotechnology
Beijing Institute of Genomics
Beijing Institutes of Life Science (preparatory)
Chengdu Institute of Biology
Guangzhou Institute of Biomedicine and Health
Institut Pasteur of Shanghai
Institute of Biophysics
Institute of Botany
Institute of Genetics and Developmental Biology
Institute of Hydrobiology
Institute of Microbiology
Institute of Psychology
Institute of Zoology
Kunming Institute of Botany
Kunming Institute of Zoology
Qingdao Institute of Biological Energy and Bioprocess Technology
Shanghai Institute of Mataria Medica
Shanghai Institutes for Biological Sciences
South China Botanical Garden
Tianjin Institute of Industrial Biotechnology (preparatory)

[463] CAS website. http://english.cas.cn/CASI/; see also the Guide to CAS Institutes http://english.cas.cn/CASI/In/200909/P020091021600391195528.pdf

Wuhan Botanical Garden
Wuhan Institute of Virology
Xishuangbanna Tropical Botanical Garden

Resources and the Environment
Chengdu Institute of Mountain Hazards and Environment
Cold & Arid Regions Environmental and Engineering Research
Guangzhou Institute of Geochemistry
Institute of Atmospheric Physics
Institute of Earth Environment
Institute of Geochemistry
Institute of Geodesy and Geophysics
Institute of Geographic Sciences and Natural Resources Research
Institute of Geology and Geophysics
Institute of Oceanology
Institute of Remote Sensing Applications
Institute of Subtropical Agriculture
Institute of Tibetan Plateau Research
Institute of Urban Environment
Institute of Vertebrate Paleontology and Paleoanthropology
Nanjing Institute of Geography and Limnology
Nanjing Institute of Geology and Paleontology
Nanjing Institute of Soil Science
Northeast Institute of Geography and Agricultural Ecology
Northwest Institute of Plateau Biology
Qinghai Institute of Salt Lakes
Research Center for Eco-Environmental Sciences
Shenyang Institute of Applied Ecology
South China Sea Institute of Oceanology
Wuhan Institute of Rock and Soil Mechanics
Xinjiang Institute of Ecology and Geography
Yantai Institute of Coastal Zone Research

High Technology
Academy of Opto-Electronics
Center for Earth Observation and Digital Earth
Center for Space Science and Applied Research
Changchun Institute of Applied Chemistry
Changchun Institute of Optics, Fine Mechanics and Physics
Dalian Institute of Chemical Physics
Guangzhou Institute of Energy Conversion
Institute of Acoustics
Institute of Automation
Institute of Computing Technology
Institute of Electrical Engineering
Institute of Electronics
Institute of Engineering Thermophysics

Institute of Metals Research
Institute of Microelectronics
Institute of Optics and Electronics
Institute of Process Engineering
Institute of Semiconductors
Institute of Software
Lanzhou Institute of Chemical Physics
Ningbo Institute of Material Technology and Engineering
Shanghai Institute of Ceramics
Shanghai Institute of Microsystem and Information Technology
Shanghai Institute of Optics and Fine Mechanics
Shanghai Institute of Organic Chemistry
Shanghai Institute of Technical Physics
Shan'xi Institute of Coal Chemistry
Shenyang Institute of Automation
Shenzhen Institutes of Advanced Technology
Suzhou Institute of Biomedical Engineering and Technology
Suzhou Institute of Nano-tech and Nano-bionics
Xi'an Institute of Optics and Precision Mechanics
Xinjiang Institute of Physical and Chemical Technology

Appendix II: China's National Laboratories

China's 20 National Laboratories having a status higher than Key Laboratories. Four of these were started in the 1980s and 1990s, with another batch begun in 2003, and 10 more in 2006.

The first four include:

- The National Synchrotron Radiation Lab at the CAS University of Science and Technology in Hefei, Anhui province (1984).
- The Beijing Electron Positron Collider at the CAS Institute of High Energy Physics in Beijing (1988).
- The National Heavy Ion Accelerator Lab at the Institute of Modern Physics in Lanzhou, Gansu province (1991).
- The National Lab for Materials Science at the CAS Institute of Metals Research in Shenyang, Liaoning province (2000).

The six established in 2003 include:

- The National Lab for Physical Sciences at the Microscale at the University of Science and Technology, Hefei.
- The National Laboratory for Information Science and Technology at Tsinghua University, Beijing
- The Beijing National Lab for Molecular Science, jointly operated by Peking University and the CAS Institute of Chemistry in Beijing.
- The Wuhan National Lab for Optoelectronics, jointly operated by Huazhong University, the Wuhan Research Institute of Posts and Telecommunications/Fiberhome Group;
- CAS Wuhan Institute of Physics and Mathematics, and the 717 Research Institute of the China Shipbuilding Industry Corporation;
- The National Lab on Condensed Matter Physics at the CAS Institute of Physics, Beijing.

The final group, approved in 2006, in conjunction with the launching of the MLP, and now in various stages of development, includes:

- The Qingdao National Lab for Marine Science and Technology at the Ocean University of China, Qingdao, Shandong province.
- The National Lab for Aeronautics and Astronautics at the Beijing University of Aeronautics and Astronautics.
- The National Lab for Major Disease Research at the Chinese Academy of Medical Sciences, Beijing
- The National Lab for Magnetic Confinement, jointly operated by the CAS Hefei Physical Sciences Research Institute and the Southwest Nuclear Physics Research Institute Center for Fusion Science of the Southwest Institute of Physics.

- The National Lab for Clean Energy at the CAS Dalian Institute of Chemical Physics, Dalian, Liaoning province.
- The National Lab for Naval Architecture and Ocean Engineering at Shanghai Jiaotong University.
- The National Lab for Microstructures as Nanjing University
- The National Lab for Bio-macro-molecules at the CAS Institute of Biophysics in Beijing.
- The National Lab for Modern Rail Transportation at Southwest Jiaotong University, Chengdu, Sichuan province.
- The National Lab for Modern Agriculture at the China University of Agriculture, Beijing.
- The National Lab on Equipment Manufacturing Science and Technology at the Xi'an Jiaotong University in Xi'an, Shaanxi province.

Appendix III: US-China Scientific Cooperation

Additional areas of government-sponsored scientific cooperation between China and the United States not discussed in the main body of the report are listed below. These cases provide a flavor to what has become a fairly extensive government to government S&T relationship.[464]

Environmental Protection. There have been formal US-PRC agreements in the area of environment protection since 1980.

- In 2003, the US EPA and the State Environmental Protection Administration (SEPA) of China (now, the Ministry of Environmental Protection, or MEP) signed a new MOU which provides for the establishment of a Joint Committee on Environmental Cooperation, and which contained annexes on air pollution, water pollution, and pollution from persistent organic pollutants (POPs) and other toxins. Subsequently, two other annexes have been signed, one on hazardous wastes and most recently one on environmental law and enforcement.

- In 2006, EPA also signed in MOU with the Ministry of Science and Technology which has led to cooperation in the areas of drinking water security, new environmental technologies, and green communities and sustainability, and in 2007, an MOU was signed with the Ministry of Water Resources for cooperation in source water protection and watershed management.

- An MOU between EPA and the Administration on Quality, Standards, Inspection and Quarantine (AQSIQ) was also signed in 2007 dealing with environmental standards, including those pertaining to international trade. In addition, EPA conducts activities outside of the formal MOU and has conducted projects with a variety of central and local government agencies in China.

A number of discrete projects have been carried out under these agreements (there were some 24 projects under the air pollution annex alone during 2006 and 2007), often involving academic or commercial partners, or participants from other government agencies. These activities have involved joint research, workshops, and training. There has been a strong technical assistance thrust to many of these activities to help China build capacity in the science and policy needed to enhance environmental governance in the face of its severe environmental problems. A number of new approaches to environmental management in China, including a recently announced sulfur dioxide emissions trading program and a national water discharge permit program, have grown out of a background of bilateral cooperation going back a decade or more.

[464] This section is taken from Richard P. Suttmeier, "From Cold War Science Diplomacy to Partnering in a Networked World: 30 Years of Sino-US Relations in Science and Technology." Unpublished paper presented at the 2009 Hixon Forum, "Science and Technology in the Making of Modren China," Harvey Mudd College, February 27-28, 2009. http://china-us.uoregon.edu/papers.php

Agriculture. Agreements between the USDA and the Ministries of Agriculture and Science and Technology (MOST) have led to a wide range of research and technical assistance activities in the area of agricultural science and technology. A US-China High-Level Biotechnology Working Group (BWG) provides a forum for the two sides to exchange views on regulatory and biosafety issues associated with agricultural biotechnology, and involves not only the Chinese Ministry of Agriculture on the Chinese side but also the Administration of Quality Supervision and Inspection and Quarantine (AQSIQ), the Ministry of Commerce, and the Ministry of Public Health. The BWG also includes a

Technical Working Group on the environmental and food safety implications of agricultural biotechnology which, in addition to the agencies above, also include representation from the Shanghai Academy of Agricultural Sciences, The Chinese Academy of Agricultural Sciences, The China Center for Disease Prevention and Control, The Chinese Academy of Sciences, Fudan University, and various provincial departments of agriculture. A variety of other activities in the area of food safety have occurred, including discussions of food safety regulatory systems with the National Development and Reform Commission (NDRC) and the establishment of two joint food safety research centers.

Other agriculture related activities include cooperation on ethanol and biofuels development, forestry management, soil and water conservation (including cooperation with The Chinese Ministry of Water Resources and the Chinese Academy of Sciences), plant and animal health, control of invasive species, agricultural economics and statistics, nutrition issues, and cooperation on research and management of individual plant and animal species. USDA also cooperates with The Chinese Academy of Agricultural Sciences in the establishment and operation of a Sino-US Biological Control Lab in Beijing. Under its Scientific Cooperation and Exchange Program, USDA has supported the exchange of some 1,500 US and Chinese scientists since the program was initiated in 1978.

Cooperation on biofuels has been advanced by the signing of a new annex to the protocol between USDA and MOST in 2008. It calls for the establishment of a joint research center between the Agricultural Research Service and the Institute of New Energy Technology of Tsinghua University, the exchange of graduate students, and the convening of research seminars. Cooperation will focus on genomics and the genetic engineering of crops and the development of biological catalysts used in fermentation.

Cooperation in the areas of water resources and resource conservation has also increased, again involving joint research projects, the establishment of joint research centers (e.g., for efficient irrigation, intensive agriculture and nonpoint source pollution control, grazing land ecosystem restoration, and soil and water conservation), and student and scholar exchanges.

A review of the bilateral activities in the field of agriculture shows a wide range of research and technical exchange involving a broad spectrum of institutions in the two countries. US investigators have had access to data from distinctive ecosystems in many parts of China and have interacted with elite Chinese scientists in cutting edge areas of agricultural science and technology as well as with local experts from a broad variety of regional institutions. The Chinese side, in turn, has been exposed to the technology of modern agricultural research which has contributed to the building of human resource and institutional capabilities. The relationship has also involved bilateral engagement on important policy issues dealing with food safety, regulatory arrangements for biotechnology, and the relationships between agriculture and energy. The relationship has produced many mutually beneficial results and is now poised for deeper and more sustained joint research efforts.

Basic Science. A Basic Sciences protocol formalizes US National Science Foundation (NSF) relations with the Chinese Academy of Sciences, the Chinese Academy of Social Sciences, The Ministry of Education, and the National Natural Science Foundation of China (NSFC). A second protocol involving the US Geological Service as well as the NSF on the US side, and the NSFC, the China Earthquake Administration (formerly the State Seismological Bureau), and the Ministry of Construction on the Chinese side. Under these protocols, NSF has supported a broad range of collaborative research in basic science, engineering, and the social sciences which amounted to more than $16 million of spending during 2006-7. NSF has cooperated with China on projects dealing with disaster prediction and mitigation, and structural engineering and the mitigation of hazards. Beyond the work under the protocols, however, there are a variety of other activities. In recent years, NSF has emphasized the importance of educational programs in its relations with China and has supported summer research opportunities for American graduate students in China. China also figures prominently in the NSF PIRE (Partnership for International Research and Education) program which provides for multi-year institutional support for international collaboration involving students and faculty, often on multilateral projects. (Insert note that the UCSB's participation in the cooperation agreement with the Dalian Institute of Chemical Physics, noted above, is supported by PIRE). Following the completion of an NSF delegation to China in the physical sciences in 2007, the two sides have initiated a major joint research project in chemical sciences, an area of Chinese strength.

China participates as an associate member in the NSF Integrated Ocean Drilling Program, and this past year NSF and NSFC laid the foundations for a multidisciplinary project on climate change. The relationship between NSF and NSFC is especially cordial; as noted above, NSF inspired the establishment of NSFC and has provided ongoing counsel in the management and operation of a basic research-oriented funding agency. In 2004, the two agencies cooperated in convening a forum on basic science for the next 15 years in conjunction with the preparation of China's MLP, discussed in the previous chapter. NSF also sponsors a variety of high-level workshops and symposia in cutting-edge work areas of interest to the two countries, such as recent workshops on nano-scale standards and computer science.[2] As a measure of China's growing importance to NSF, NSF established a representative office in Beijing in 2005.[3]

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[2] A complete list of workshops includes: bio-complexity, nanotechnology, biomechanics, mechanics, green chemistry, chemical engineering, history of life, computer and information sciences, nano-structural materials, climate change, and microgeobiological sciences.

[3] In addition to NSF, other agencies now maintain representatives in Beijing, including DOE, FAA, and units of HHS. These are in addition to seven officers in the Embassy's science counselor's office.

The US Department of Energy (and its predecessor agencies) has also long been involved with China in areas of basic research, most notably through agreements for cooperation in high-energy physics and nuclear fusion. The high-energy physics agreement was first signed in January, 1979 and has provided for close cooperation between high-energy physics communities in the two countries, especially in support of the establishment and recent upgrading of the Beijing Electron Positron Collider, an important facility which allows for world-class research in China. The largest current collaboration under this agreement is the construction of unique facilities, scheduled for completion in 2011, for studying neutrino oscillations at the site of the Daya Bay nuclear power plant complex. The US is contributing half of the cost of the detectors, while the Chinese side is paying for the construction and civil engineering. DOE has also assisted in the design and construction of other major facilities including the new Shanghai Synchrotron Radiation Facility and the Chinese Spallation Neutron Source noted above.

The *Protocol on Cooperation in the Fields of Nuclear Physics And Controlled Magnetic Fusion Research* was originally signed in 1983. Activities under the protocol have focused mainly on fusion and have involved training, cooperative research, and design assistance to China in the construction of its new EAST tokamak facility at the Institute of Plasma Physics of the Chinese Academy of Sciences in Hefei. This unique facility, which was tested and achieved its first plasma in September, 2006, has led to the increase of cooperative, mutually beneficial bilateral activities. With China joining ITER (International Thermonuclear Experimental Reactor), opportunities for bilateral cooperation on multilateral issues have also increased. China's increasing ability and willingness to pay for large, complex and expensive facilities is one of the reasons why it has become an increasingly attractive partner for international cooperation.[4]

Medicine and Public Health. Cooperation in the areas of medicine and public health also goes back to 1979 with the signing of the *Protocol for Cooperation in Science and Technology of Medicine and Public Health* which provided for cooperation in public health, biomedical research, health care, and health policy. Today, the US Department of Health and Human Services (HHS) maintains agreements with both the Ministry of Public Health and MOST. In addition, the health area has expanded and become quite active in recent years in light of the AIDS epidemic, and in the wake of the SARS outbreak. In 2002, HHS and the Ministry of Health signed a memorandum of understanding for cooperation in fighting AIDS through prevention activities, treatment, and research. As part of the US Emergency Plan for AIDS Relief, activities include research on vaccines, the development of testing kits for rapid diagnosis, surveillance, and innovative treatments.

A second MOU, for collaboration on emerging and reemerging infectious diseases, was signed by the two parties in 2005. It provides for a higher profile HHS presence in China with staffing from the Centers for Disease Prevention and Control (CDC), and supports Chinese capacity building through laboratory development, surveillance, enhanced epidemiology, and the establishment of China's own CDC. In addition, HHS and MPH maintain an agreement on integrative and traditional Chinese medicine.

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[4] Although not discussed here, this is true in other fields as well, as seen, for instance, in astronomy with the construction of the LAMOST (Large Sky Area Multi-Object Fibre Spectroscopic Telescope) facility.

The National Institutes of Health are also actively involved with China, with 18 institutes and centers having ongoing research with China. Chinese researchers have been consistently the most numerous visiting scientists at NIH laboratories (in 2007, there were 630), and have also been recipients of NIH extramural research awards. Extramural research grants have also supported a wide range of cooperative projects involving investigators from US and Chinese institutions. NIH employs one scientist in Beijing who coordinates with the Chinese CDC, the Chinese Academy of Medical Sciences, and the Chinese Academy of Sciences in facilitating research on a variety of diseases, and plays an important role in the implementation of the agreement on emerging and reemerging infectious diseases; some $4 million has been spent by NIH on influenza research in China. In addition, NIH has also had its own long-standing MOU with the Chinese Academy of Sciences for cooperation in basic biomedical research. The MOU was first signed in 1983 and was amended in 2005. Among other things, it calls for jointly funded research training in the US, and continuing support for researchers once they return to China. It is also intended to encourage CAS scientists to collaborate more actively with Ministry of Health entities to raise the level of research capacity in the fields of medicine and public health.

Atmospheric and Marine Science. The US National Oceanic and Atmospheric Administration conducts activities with China under two protocols, one on atmospheric science and technology with the Chinese Meteorological Administration (CMA), and one on marine and fisheries science and technology with the State Oceanic Administration of China. A number of working groups have been established under each protocol. In the atmospheric science area, NOAA has played an important role in helping to modernize CMA through training, instrumentation, and software. Meanwhile China itself has significantly increased its capabilities with the acquisition of more advanced radars, satellites, high-performance computers, and increasingly sophisticated basic science. Areas of cooperation include numerical weather prediction, atmospheric chemistry, and the relationship between monsoons and climate. Under the Marine sciences protocol, there is also work on the role of oceans in climate change, and working groups on oceanographic data and information, living marine resources, integrated coastal management, and polar sciences.

Given its size, location, and topography, China figures prominently in earth observation activities of interest to NOAA, and NOAA's leadership in the science and technologies of earth observations makes it of considerable interest to China. China and the US are both important members of the World Meteorological Organization (WMO), and extend their bilateral cooperation into multilateral settings. China and the US also work together in the GEOSS (Global Earth Observation System of Systems).

Other Programs. *W*ith regard to metrology, the National Institute of Standards and Technology (NIST) maintains agreements with the Chinese Academy of Sciences for cooperation in the fields of chemistry, physics, materials, and engineering measurement sciences. The Department of Commerce, of which NIST is a part, has an agreement with the Chinese Administration for Quality Supervision, Inspection and Quarantine (AQSIQ) in the areas of metrology, documentary standards, accreditation, and information technology. A variety of workshops and exchanges have taken place under these agreements. In addition, NIST has hosted Chinese guest researchers in its laboratories under its Foreign Guest Researcher Program. During FY 2006 and 2007, there were 191 Chinese working with NIST counterparts on projects of mutual interest.

As noted above, USGS participates with NSF and the China Earthquake Administration and the Natural National Science Foundation of China in the implementation of a protocol on earthquakes. In addition, USGS also has protocols on earth sciences, water resources, and mapping. The Department of Transportation has agreements with Chinese counterparts in the areas of railroads, traffic safety, highway cooperation, and cooperation on innovative technologies. A notable exception in the range of government science activities where cooperation has failed to materialize is that of space science and technology, discussed further below.