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

[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

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[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.

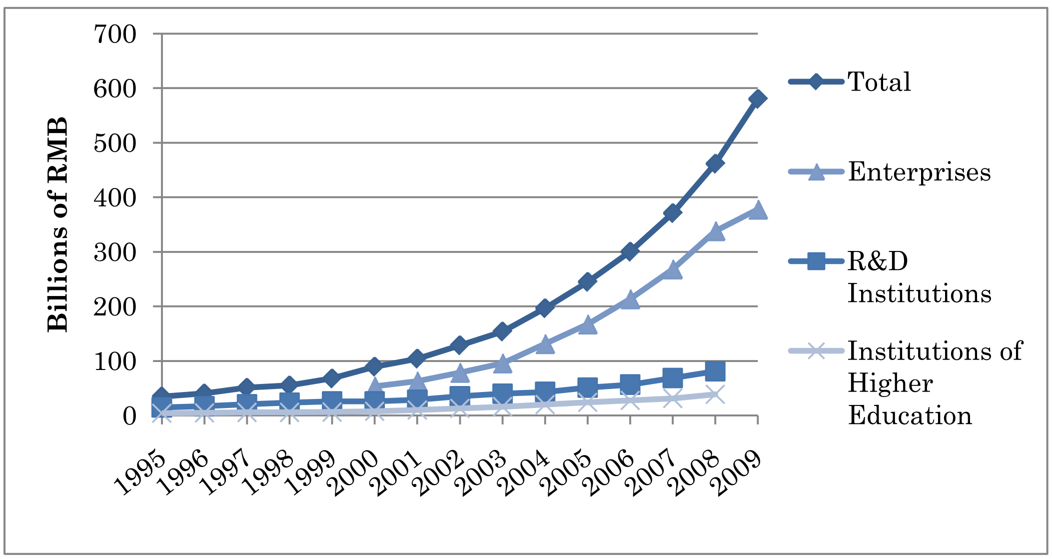
As these choices suggest, debates over the direction of Chinese science are far from abating. Scientists, businessmen, and officials offer different solutions to a range of problems in different technology sectors and scientific fields, with the result that the future of the innovation system is contested. 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.

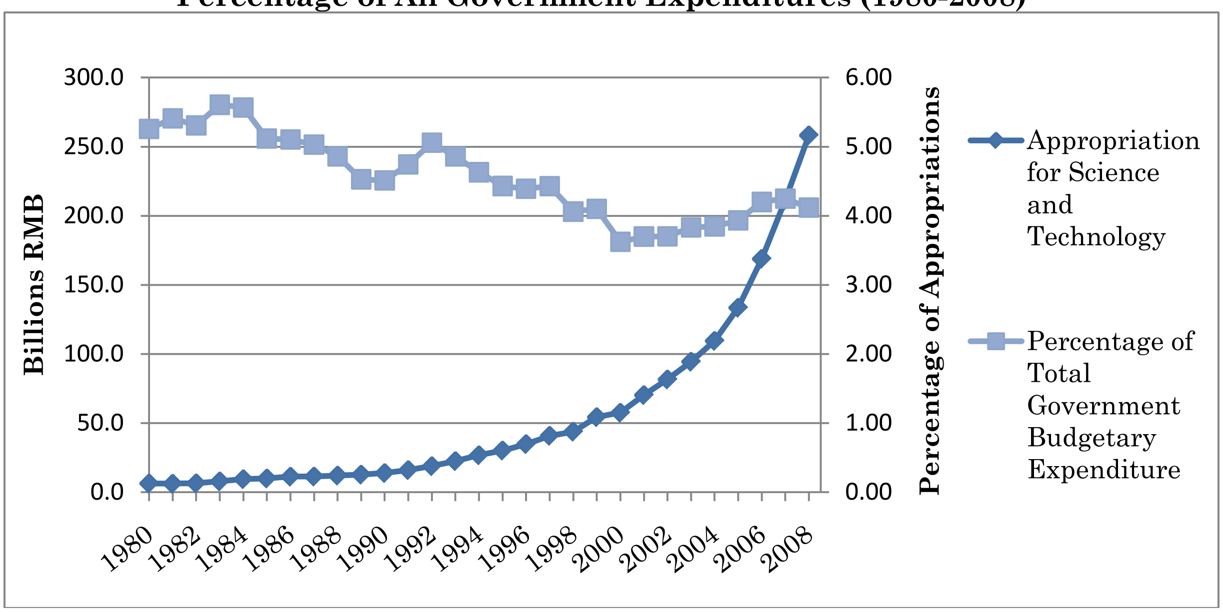
[17] According to a report by China's National Bureau of Statistics, "Di'er ci quanguo kexue yanjiu yu shiyan fazhan ziyuan qingcha zhuyao shuju gongbao" (the second nationwide science research and development resources inventory: public report on important statistics), November 22, 2010. http://www.stats.gov.cn/tjgb/rdpcgb/qgrdpcgb/t20101122_402684868.htm

[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.

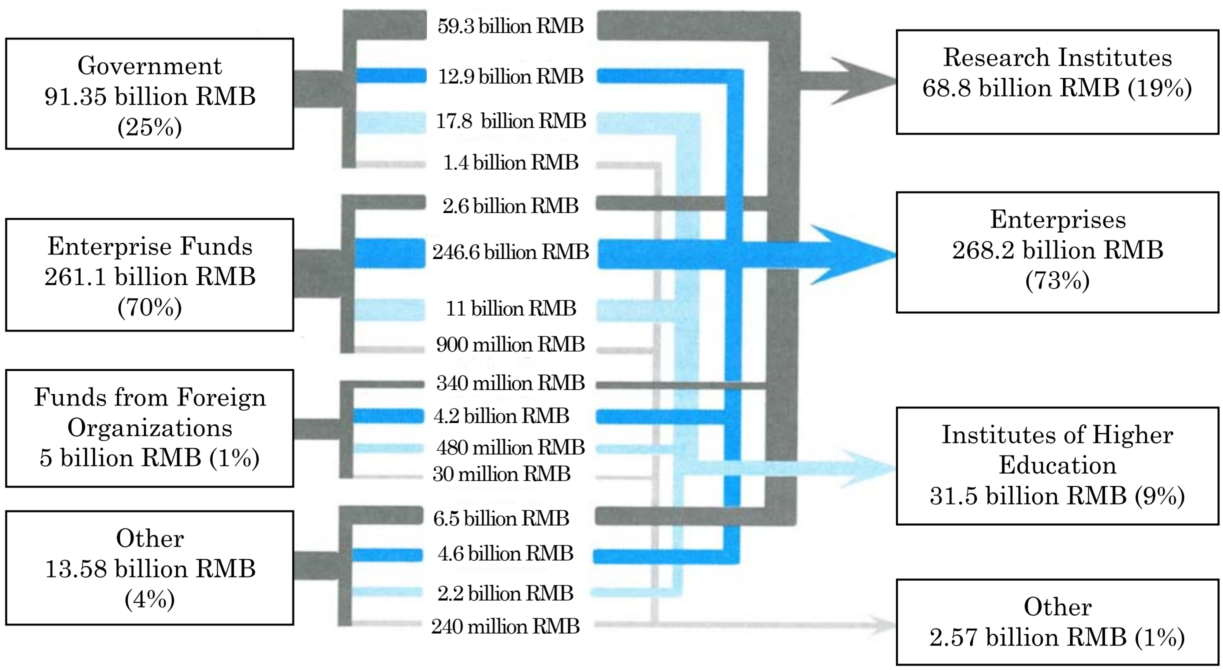
[19] Chinese figures are calculated based on 2007 statistics, when the government spent .37 percent of GDP on R&D. Assuming 25% of R&D spending derived from the Chinese government in 2009, as it did in 2007, China spent .4 percent of GDP on R&D. R&D statistics are from the China Ministry of Science and 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]

R&D Funding Sources (total: 371 billion RMB) R&D Funding Received (Performers)



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

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[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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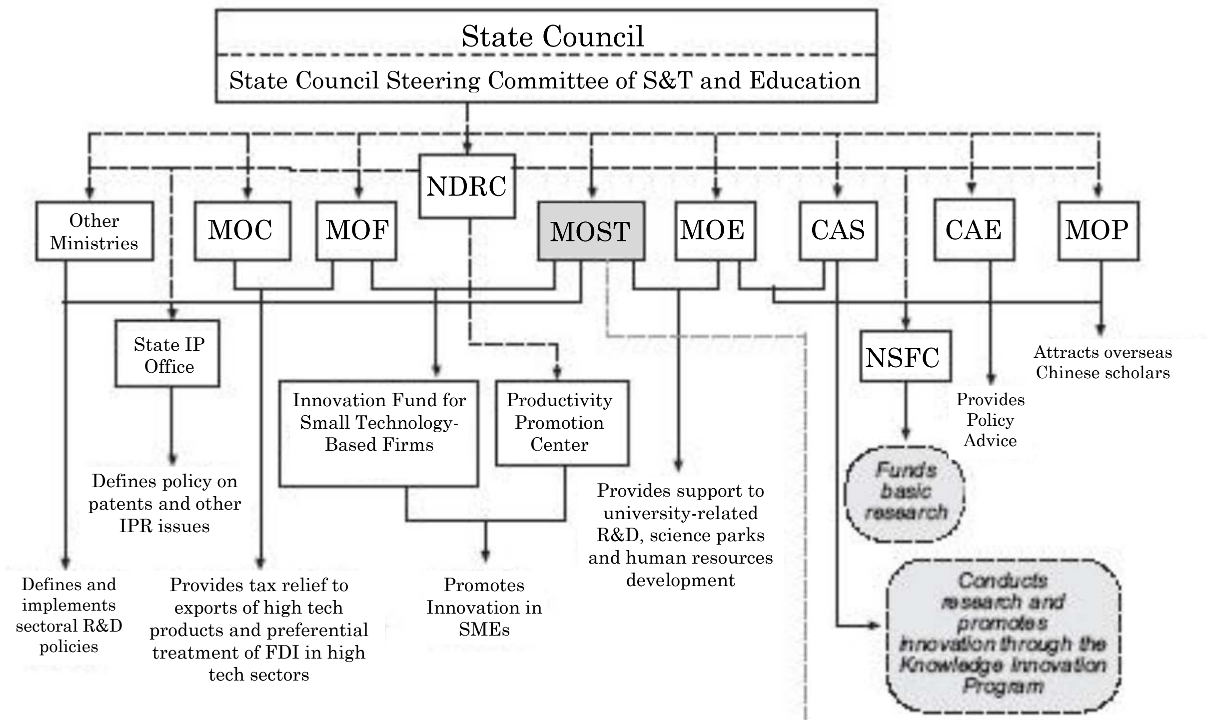
[36] National Bureau of Statistics, "Di'er ci quanguo kexue yanjiu yu shiyan fazhan ziyuan qingcha zhuyao shuju gongbao."
[37] Based on National Bureau of Statistics data provided separately on R&D expenditures and national program expenditures.
[38] In 2008, the OECD reported that local governments 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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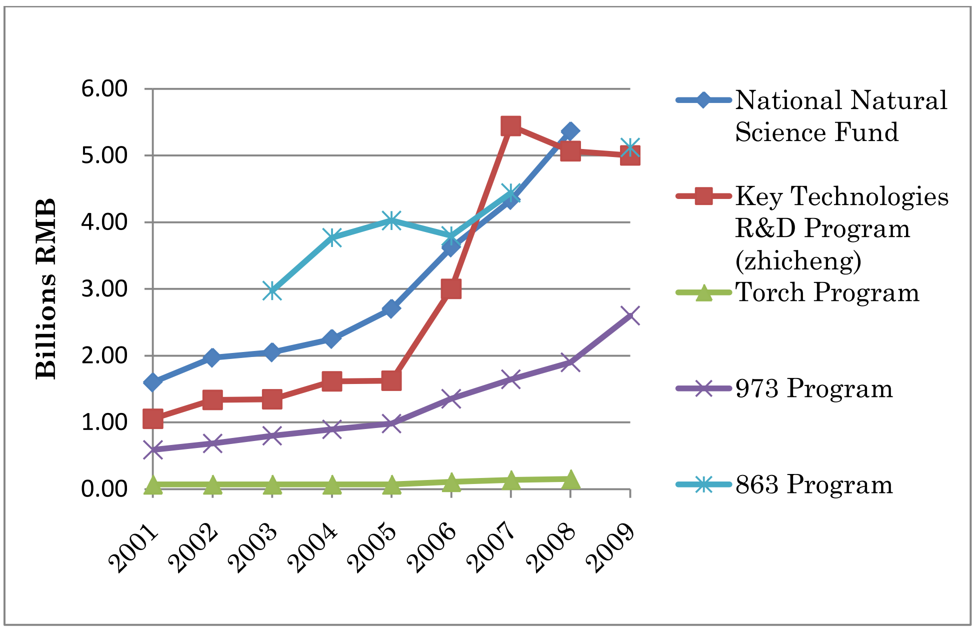
[41] See, for example, Chinese Academy of Engineering News, "Guanyu wo guo 'shierwu' xinxihua fazhan de jiben silu" (basic thinking on the 12th Five Year Plan's informatization development), *Keji yu Chuban*, Issue 7, 2010, p. 62.

[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.

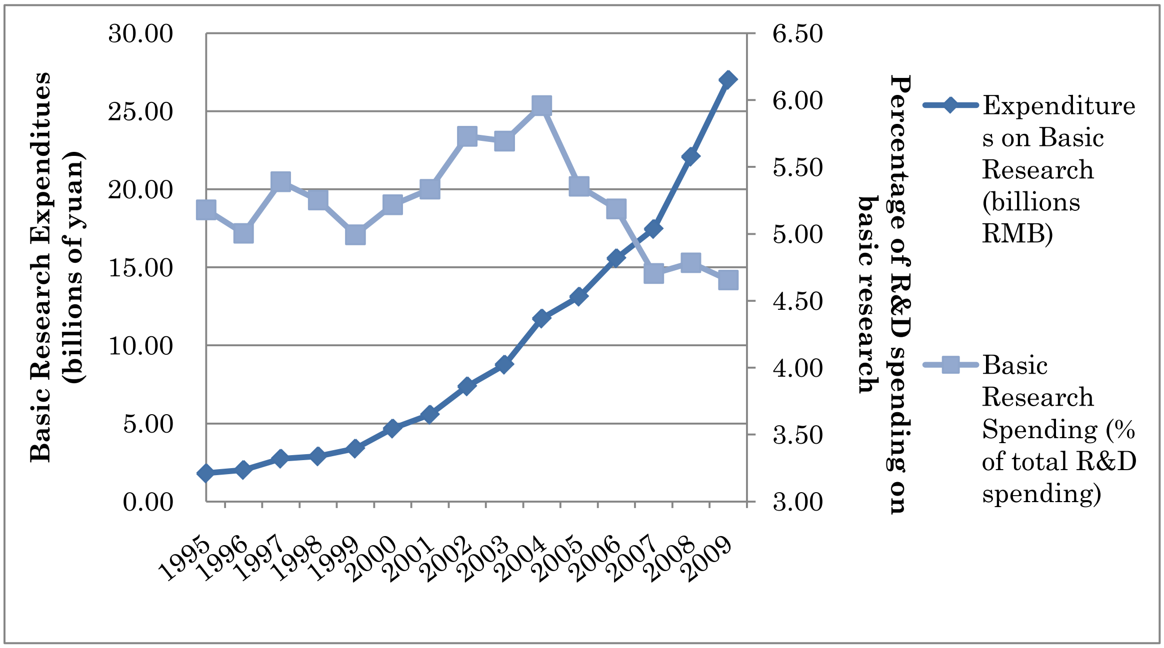
all going to research institutes and universities. Approximately 90 percent of the funding support for 973 comes from government sources.[56]

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.

[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

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[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

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[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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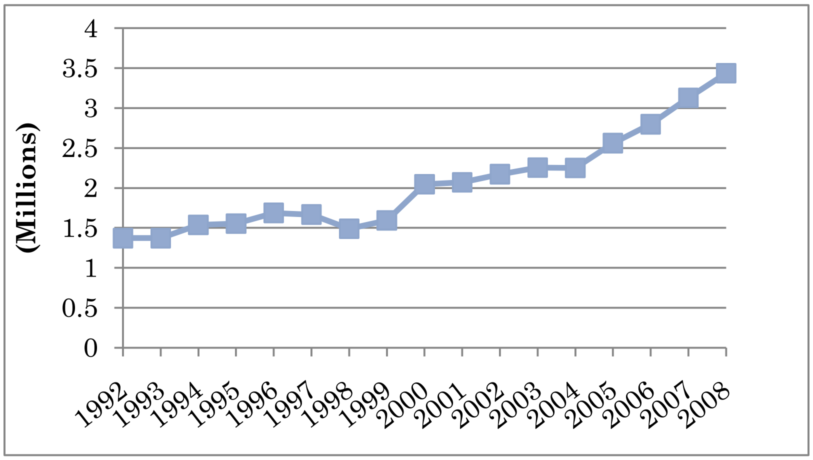
[79] For a full list, see the CAS English website, "Big Science Facilities," http://english.cas.cn/Re/Fac/.
[80] The discussion which follows is based on data for 2009 found in the November 22, 2010 report from the National Bureau of Statistics, and available at http://www.stats.gov.cn/tjgb/rdpcgb/
[81] 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

[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

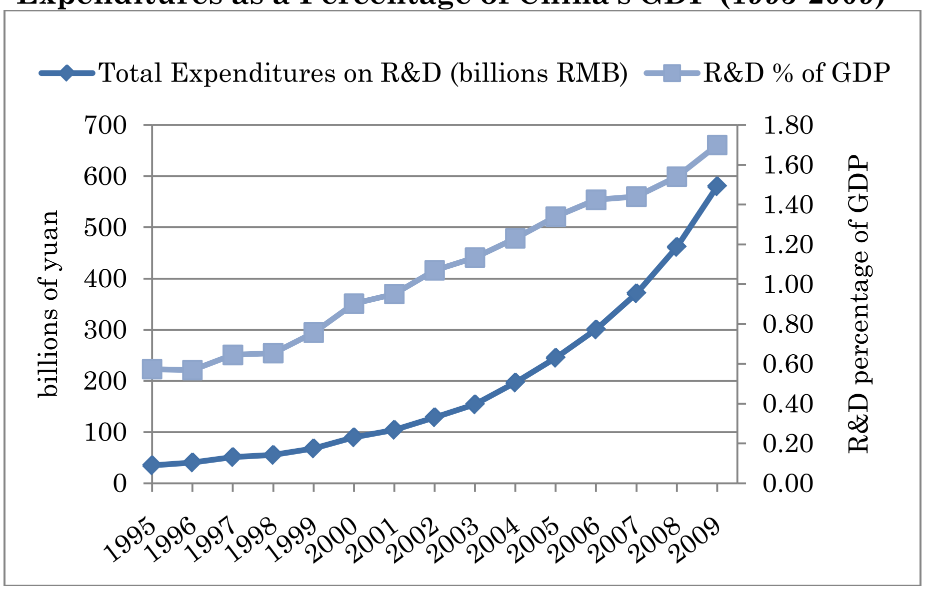
realize the goals.[89] As such, it is an attempt to pull together and better integrate the national programs of the past, significantly raise their funding, and develop an integrated policy framework—including a "web of industrial policies"—to support the idea of "indigenous innovation."[90]

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]

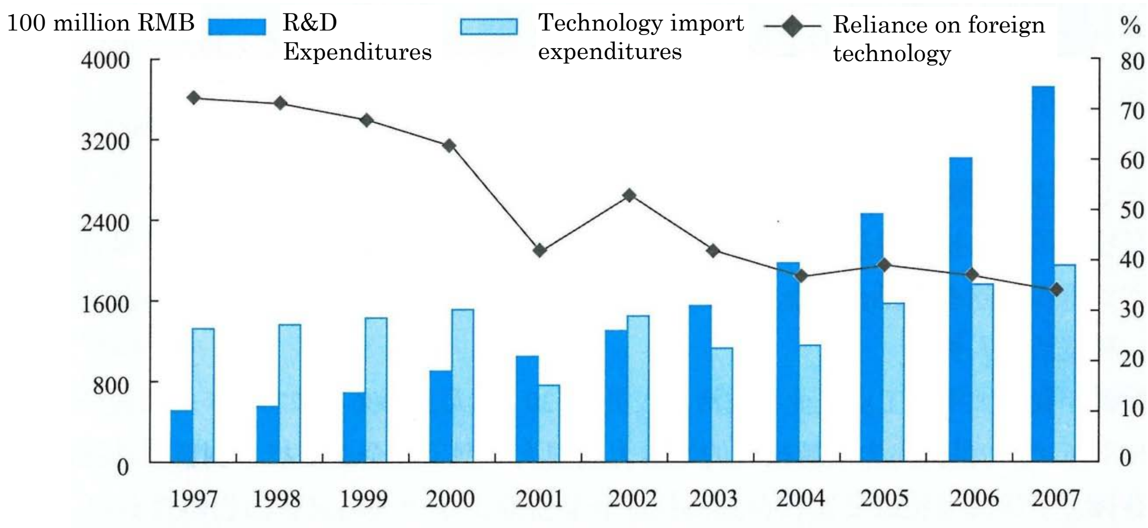
Figure 8: PRC National R&D Expenditures and Expenditures as a Percentage of China's GDP (1995-2009)[93]



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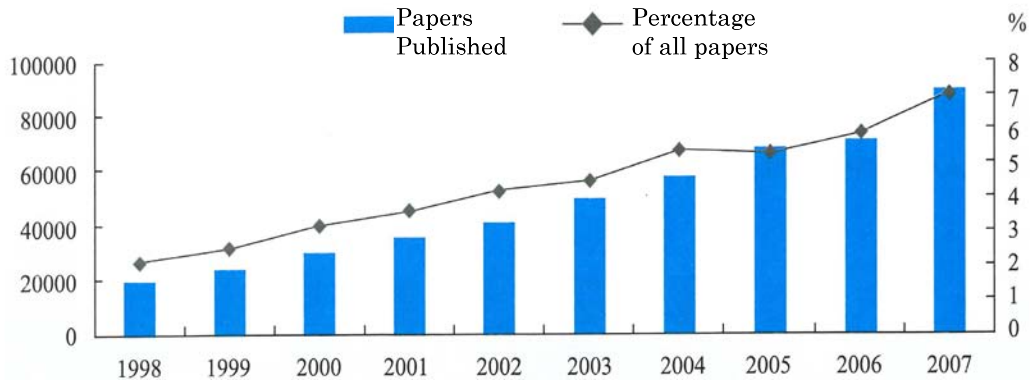
[94] China Ministry of Science and Technology, *China Science and Technology Indicators 2008*, (Scientific and Technical Documents Publishing House: Beijing, 2009), p. 87.

[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.

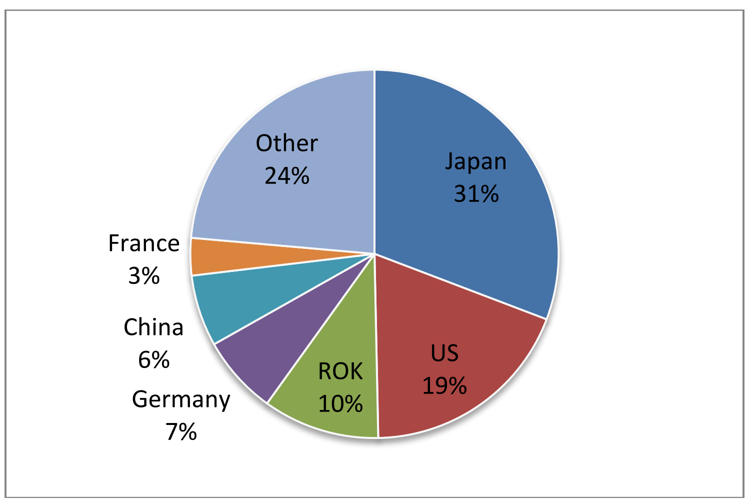
[97] The United States, by comparison published 2,974,344 papers and had 44,669,056 citations during the same time span. The value of using these numbers as a judge of Chinese scientific prowess must be tempered by reports of significant levels of plagiarism and falsified data in published papers, described

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

[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

[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.