feature article

China's 15-year science and technology plan

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As China implements its plan to improve scientific innovation, it will need to solve such political and economic problems as finding the proper balance between indigenous efforts and engagement with the global community.

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In January 2006, China initiated a 15-year "Medium- to Long-Term Plan for the Development of Science and Technology." The MLP calls for China to become an "innovation-oriented society" by the year 2020, and a world leader in science and technology (S&T) by 2050. It commits China to developing capabilities for "indigenous innovation" (*zizhu chuangxin*) and to leapfrog into leading positions in new science-based industries by the end of the plan period. According to the MLP, China will invest 2.5% of its increasing gross domestic product in R&D by 2020, up from 1.34% in 2005; raise the contributions to economic growth from technological advance to more than 60%; and limit its dependence on imported technology to no more than 30%. The plan also calls for China to become one of the top five countries in the world in the number of invention patents granted to Chinese citizens, and for Chinese-authored scientific papers to become among the world's most cited. In all likelihood, the MLP will have an important impact on the trajectory of Chinese development; it thus warrants careful attention from the international community.

Preparation for the MLP began in 2003. At that time more than 2000 scientists, engineers, and corporate executives were mobilized into a program of "strategic research" to identify critical problems and research opportunities in 20 areas considered to be of central importance for China's future. Box 1 lists those areas, which include advanced manufacturing, agriculture, basic science, energy, human resources, and national defense.

In contrast to earlier planning efforts, the preparations—at least at the outset—were remarkably open. In particular, they included social scientists (mainly economists) and foreign scholars. Eventually, that openness gave way to a more secretive process in which the bureaucracy massaged the reports of the 20 working groups, attempted to reach compromises, and drafted the public version of the MLP. By most accounts, the drafting process was contentious and unusually drawn out. At one point, the onerous process of narrowing the plan's focus and setting priorities required direct intervention by China's premier, Wen Jiabao.

Box 1. The 20 topics of strategic research in China's 15-year science plan

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

Technological problems

The MLP is remarkable in a variety of ways. It builds on important policy initiatives launched in the past 25 years, including the 1995 commitment to strengthen the nation through science, technology, and education and the more recent notion of empowering the nation through talent. Under rubrics such as those, China has made great efforts in the past several years to advance its science and education. As figure 1 shows, those efforts include increased expenditures on R&D, and they have led to growing numbers of scientists and engineers engaged in R&D (figure 2) and increased enrollments in higher education (figure 3). Also, as evidenced by new initiatives pertaining to intellectual property law, technology standards, and venture capital, the nation has begun to take seriously the notion of technological innovation as a complex, systemic problem.

Despite the many signs of progress in China's S&T, the MLP comes at a time of serious concern about the nation's de-

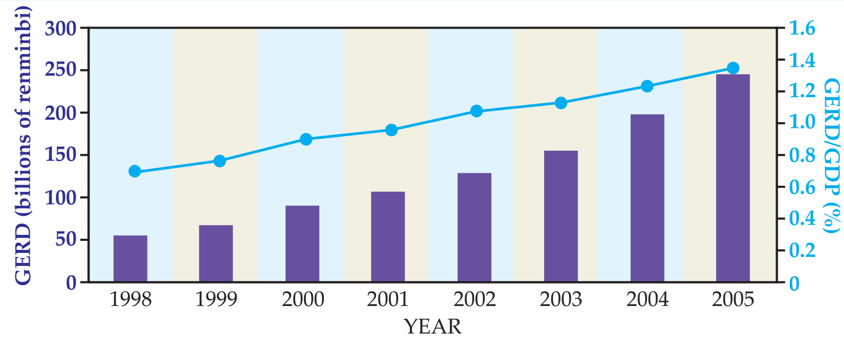

Figure 1. China's gross expenditure on R&D (GERD) has steadily grown since 1998, both in absolute terms (purple histogram bars) and as a percentage of the gross domestic product (blue curve). Absolute expenditures are given in renminbi: 1 US dollar is worth about 8.3 RMB. (Source: ref. 9.)

velopment. China's leaders have pledged to make the nation an "overall well-off society" (*quanmian xiaokang shehui*), with a per-capita income of $3000 by 2020, up from $1000 in 2002. Achieving that goal will require continued rapid economic growth. The leadership, however, is aware that the high-speed growth of the past 25 years—with its overinvestment, inefficient use of resources, and the devastating effect on the environment—cannot be sustained. The path to creating the overall well-off society will necessarily be characterized by technological innovations supporting greater efficiency and productivity, and institutional innovations supporting improvements in governance—greater market discipline and integrity, less government corruption, and greater administrative accountability.

The MLP addresses four critical problems in China's scientific and technological development. First, despite the country's remarkable economic accomplishments, its record of innovation in commercial technologies has been weak, even considering recent improvements in its patenting performance. Instead, its dependence on foreign technology has grown consistently over the past 20 years. In part, that dependence was a consequence of the state's "market for technology" strategy, which was intended to entice multinational corporations to transfer technology in return for market opportunities. The policy, arguably, was quite successful in helping to make China the manufacturing center of the world and in stimulating the impressive rapid growth of China's high-technology exports.

However, Chinese leaders have concluded that the policy may have run its course. It has become increasingly obvious to them that those who own the intellectual property, and who control technical standards, enjoy privileged positions in, and profit most from, international production networks. In addition, as a result of continued conflicts with the US and other countries over intellectual property rights and standards, China has concluded that current patterns of control over those areas may not serve China's interests. Rather, they work to serve the international leaders in innovation. Thus, the Chinese industrial economy of the 21st century should, in this view, set its own standards and generate and incorporate its own IPR.[1] Hence the emphasis on indigenous innovation and the need to create an innovation-oriented society.

Second, Chinese technological capabilities have been failing to meet the nation's needs in such areas as energy, water and resource utilization, environment protection, and public health. The negative environmental consequences of 25 years of rapid economic growth cannot be overestimated. And continued environmental degradation over the next 15 years, such as may result from the controversial Three Gorges Dam shown in figure 4, would make a mockery of any claims that an overall well-off society had been achieved—whether or not per-capita gross domestic product (GDP) targets are reached. China's quest for energy will only increase in the coming years and will require new conservation technologies, novel energy sources, and the procurement of more conventional energy supplies. In short, broad areas of social needs cannot possibly be managed without increasingly sophisticated technology.

Third, the technological challenges of providing for the national defense furnish another powerful impetus for the initiation of the MLP. Despite China's nuclear weapons and space achievements, its overall capability for defense-related technological innovation has, until recently, not been formidable. As with civilian production technology, the modernization of Chinese military technology has largely depended on imports from abroad. China has come to realize the importance of dual-use technologies, which can be utilized for peaceful purposes or in 21st-century high-technology warfare, and the country has begun to exploit the opportunities that dual use offers. But imported dual-use technology, especially more sophisticated know-how, is subject to export

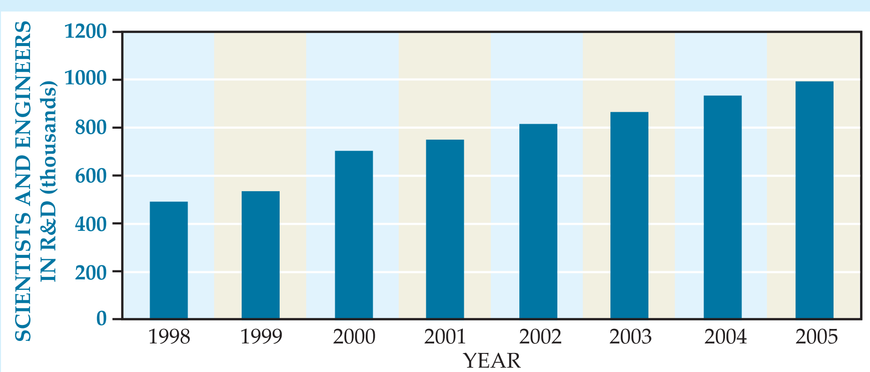

Figure 2. The number of scientists and engineers engaged in R&D in China has increased yearly since 1998. (Source: ref. 9.)

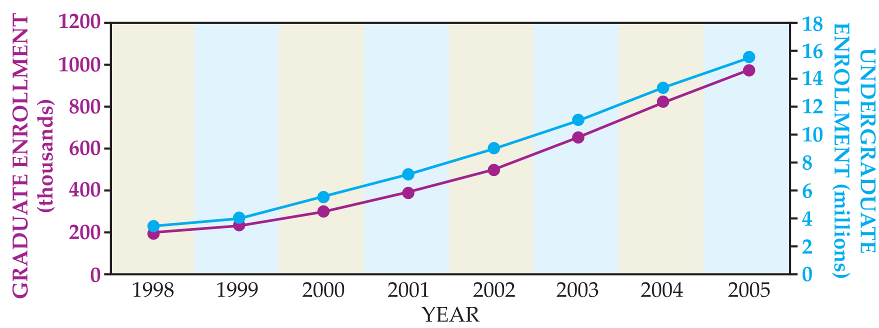

Figure 3. Student enrollments in Chinese higher education have risen since 1998 at both the graduate (purple) and undergraduate (blue) levels. (Source: ref. 9.)

restrictions—above all from the US. Hence, foreign suppliers would be an unreliable source of critical technologies; again, the need for indigenous innovation seems self-evident.

Science challenges

The fourth critical problem addressed by the MLP is the state of Chinese science. As with the nation's technology, Chinese science has contained its disappointments. Despite the swelling ranks of research personnel and increasingly generous funding, the research system's performance has not lived up to expectations. Many of China's best and brightest have sought career opportunities abroad, and despite an array of incentives offered by various national and local entities, China has had difficulty attracting them back. True, some overseas-based Chinese scientists are concerned about the development of S&T in their native country and have contributed in various ways. But the way overseas Chinese talent is used at home has occasionally been controversial. In some cases, the high salaries and material incentives used for recruitment to Chinese institutions have been abused. Researchers have enjoyed the salaries without fulfilling the obligations of appointments, while their employing institutions remained satisfied to use the names and publications of those "star scientists" to improve their evaluations and qualify for increased funding.[2]

Simply stated, quantitative gains in Chinese research productivity have not always been matched by qualitative gains. The resources committed to scientific research have, in fact, led to rapid growth of Chinese-authored papers in *Science Citation Index*–cataloged journals, but their contribution as measured by citations has been disappointing.[3] China has yet to establish a research tradition that is both conducive to creative achievements and tolerant of creative failures. Scientists have often been preoccupied with quick outcomes and immediate returns, and brain drain has slowed the development of high-level scientific leadership. Research is too often derivative in nature, which wastes resources and discourages creativity and independent thinking. Scientific misconduct of various types is seemingly widespread and often covered up and protected.

Thus, when China began preparations for the MLP in 2003, it did so from a position of considerable scientific and technological progress—but progress filled with soft spots in areas of critical national need. As the importance of science and innovation for 21st-century China gained high-level political attention, the Chinese turned to their legacy of science planning as the way to move toward the nation's future aspirations. In particular, they were inspired by the most celebrated of the past science plans, the 12-year plan (1956–67), which helped lay the foundation for modern science in China. Included among the achievements of that earlier plan were China's successes in its nuclear-weapons and space (*liangdan yixing*) programs. The 12-year plan was characterized by the central government's identification of priority projects and the mobilization of resources to work on them. The same features characterize the MLP as well.

Structure and content

The MLP consists of a number of components. The first of them sets out guidelines and principles derived from the objectives of having S&T lead future economic development. One of those principles, *zizhu chuangxin* or indigenous innovation, has led to considerable confusion inside China and abroad. In its ambiguity—*zizhu chuangxin* may also be translated as independent or homegrown innovation—it has been construed by some as a regression to the self-defeating techno-nationalist notions of self-reliance (*zili gengsheng*) from the Maoist period, during which Chinese research and innovation were largely cut off from the international community and consequently were significantly retarded.

The continuous debates, inside and outside the country, over the meaning of the term led one senior official from the Ministry of Science and Technology (MOST) to suggest that it might be best simply to talk about innovation without any attached modifiers. In explicating the concept, however, the MLP points to *zizhu chuangxin* as having three components: genuinely original innovation; integrated innovation, the fusing together of existing technologies in new ways; and "re-innovation," which involves the assimilation and improvement of imported technologies.

A second component of the MLP identifies the plan's priority areas and programs. As seen in box 2, those include 11 broad key areas pertaining to national needs and 8 areas of frontier technology. Within those areas, the MLP identifies a series of priority projects. For instance, under the new-materials area of frontier technology, the plan includes work on smart materials, high-temperature superconducting technology, and energy-efficient materials.

In addition to priority areas, the MLP identifies a series of governmentally funded, conceived, and directed "megaprojects" in engineering and science (also listed in box 2). As discussed further below, those programs have been a controversial aspect of the MLP. Their inclusion, though, reflects the legacy of science planning in China, especially the continuing influence of the *liangdan yixing* programs on Chinese thinking about S&T planning. The MLP also calls for an expansion of basic research, to include development of new disciplines and interdisciplinary areas, science frontiers, and fundamental research in support of major national strategies.

Although agriculture, energy, the environment, health, and resources receive unprecedented attention in the MLP, the physical sciences underlie many priority areas such as new materials. Most of the 13 engineering megaprojects are directly related to the physical sciences; the program in core

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Figure 4. The Three Gorges Dam, being built on the Yangtze River at Yichang, China, is the world's largest hydroelectric project. It symbolizes both China's developmental aspirations and the many problems associated with the country's development trajectory. Although the power it will generate should reduce China's dependence on fossil fuels, it carries a number of economic, environmental, and national security risks.

electronic components, high-end generic chips, and basic software is an example. Physical scientists will also play an important role in the development of frontier technologies, and two of the four science megaprojects—quantum research and nanotechnology—are in the physical sciences. Moreover, protein science, another science megaproject, will take advantage of modern facilities built for nuclear magnetic resonance analysis.

A third component of the plan deals with ongoing reforms in S&T and the further development of an integrated national system of institutions supportive of research creativity and technological innovation. It highlights important objectives pertaining to the continued reform of several government research institutes, changes in the management of S&T, and the need to encourage Chinese industrial enterprises to assume a leading role in the nation's innovation system. Furthermore, it includes policies to promote industrial research and support for small and medium-sized enterprises. The new emphasis on the central role of industry reflects growing concerns that China's companies are not generating enough intellectual capital to support the introduction of new, commercially viable products and services.

An article in the Chinese *People's Daily*, for instance, calls attention to a recent survey indicating that Chinese industrial enterprises "aren't taking research and development seriously," as 75% of them do not employ anyone to conduct it.[4] The survey report points out that in Harbin, the industrial center of northeast China's Heilongjiang Province, only 8.3% of large and medium-sized enterprises state that they are spending at least 5% of sales revenue on R&D. Another 14.1% say R&D investment has reached 3% of sales. According to the article, "The report blames the system of performance appraisal of state-owned enterprises, noting that it emphasizes increasing the value of state-owned assets but lacks criteria to appraise the technological innovation of enterprises." The survey also says that of China's fiscal input on S&T, only 10% goes to support the scientific and technological innovations of industrial enterprises.

The final sections of the MLP deal with a policy framework for the plan's implementation. That framework includes preferential taxation, high-technology industry zones, and the assimilation of foreign technology. It also includes important policies to strengthen and diversify funding for S&T, make expenditures more efficient, and develop the nation's human resources for S&T. In particular, the plan recommends the cultivation of world-class senior experts, the recruitment of talents working abroad, an expanded role for scientists and engineers in industry, reforms in education to support the goals of greater creativity and innovation, and the strengthening of intellectual property protection for Chinese innovators.

Debates

The development of the MLP involved participants from across China's S&T community, touched many local and national interests, and was not without conflict. One important issue concerned the critical relationship between indigenous innovation and technology imports. Some Chinese economists argued strongly that at China's current level of economic development and comparative advantage, the MLP should focus on maintaining China's status as the world's leading manufacturing base and that the most cost-effective way to upgrade China's technological capabilities would be to continue to encourage technology transfers from multinational corporations.

Most members of the technical community rejected that thinking and argued that foreign corporations could no longer be counted on to transfer technologies, especially advanced technologies needed by increasingly sophisticated Chinese manufacturers. They claimed that China's technical gains from multinational corporations were disappointing and noted that with its accession to the World Trade Organization, China had given up some of the policy tools it had used to leverage foreign interest in Chinese investment opportunities for access to technology. In addition, China had become increasingly dissatisfied with the relative gains it was accruing from its role in the international industrial economy. The royalties Chinese firms had to pay for foreign technology cut into already slim profit margins and often seemed excessive. China certainly cannot ignore the reasoning advanced by the economists, but given the large financial and policy resources being committed to indigenous innovation in all its manifestations, it is fair to say that the advocates of a strategic S&T policy to strengthen indigenous R&D clearly have won out.

A second issue involved the selection of megaprojects and the continued relevance of the thinking behind the 12-year plan and the *liangdan yixing* programs experience. The appeal of centrally planned S&T development is not a uniquely Chinese phenomenon, but the Chinese way is distinctive in its quest for comprehensiveness and detail, as reflected in the use of the term *guihua*, or "plan," in the MLP. *Guihua* implies a strategic, comprehensive, and long-term development plan. By contrast, the Chinese *jihua*, also translated as "plan," suggests contents and procedures for an action before its implementation.

Most Chinese planners would acknowledge that the world has changed dramatically since the days of the *liangdan yixing* programs; still, the notion of centrally selected R&D objectives and centrally mobilized resources to support those objectives seems to have special appeal in Chinese political culture. In the abstract, the debate has been whether strategic plans of this sort make for good science and creative innovation in China.

At the pragmatic level, however, the debate is about the efficacy of committing substantial funding to large national projects. The discussion has been sparked in part by criticisms about the effectiveness of such national programs as the National High-Technology Research and Development Program (the so-called 863 program) and the National Basic Research Program (the 973 program). Since the majority of national programs and approximately 15% of the government's R&D expenditures are controlled by MOST, the doubts expressed about the effectiveness of national programs have inevitably been taken as criticism of the ministry as well; detractors charge that MOST champions national programs not just to meet national goals, but also as a way to enhance its budget and overall importance.

In July 2004 a group of prominent US-based Chinese life scientists criticized the 863 and 973 programs and, by implication, the inclusion of so many megaprojects in the MLP. The scientists, who were attending a symposium in Beijing, communicated to Premier Wen their belief that the funding of the biosciences in the two programs was biased and inefficient, lacked transparency, and was too often subject to the preferences of MOST officials rather than scientists.[5] They expressed concern that the success of the MLP would be compromised if too much attention and resources were concentrated on big national projects. A few months later, additional criticism appeared in a well-publicized article in *China Voices II*, a Chinese-language supplement to *Nature*.[6] US-based neuroscientists Yi Rao and Bai Lu and senior life scientist Chen-lu Tsou of the Chinese Academy of Sciences argued for changing the ways that megaprojects are organized and funded, and suggested that MOST be dissolved, or at least have its power over research funding reduced.

In the same issue of *China Voices II*, Mu-ming Poo, a US-based scientist who also serves as director of the Institute of Neuroscience of the Chinese Academy of Sciences in Shanghai, drew an analogy relating the difference between big science and little science to the operation of a planned economy as compared with a market economy.[7] Focusing on problems with the 863 and 973 programs, Poo argued that the pursuit of megaprojects diverts resources from programs supporting bottom-up, investigator-driven projects, which often produce more original research. In his view, large national projects have channeled funds to mediocre laboratories, often on the basis of personal connections and with little peer review. Those grants, in Poo's opinion, have had little impact on the direction of research or the productivity of the participating laboratories.

Criticisms such as those described above clearly have not carried the day, given the important role of the megaprojects in the MLP. Although most of the large engineering programs will not be run principally by MOST, the research programs in frontier technologies and the science megaprojects will be. A cynical interpretation of the MLP might be that, in its R&D foci, it represents only a repackaging of existing MOST programs and national programs administered by other agencies. The frontier technology program, for instance, includes the same project areas as the 863 program, except that "advanced manufacturing" replaces "automation."

Governance and accountability

The significant expansion of government funding for research and innovation promised by the MLP is raising new concerns about the performance of the research system and whether national resources are being used wisely. Although China still is a long way from democratic accountability, the recent criticisms of the research system and frequent reports of fraud and other types of misconduct in the technical community are raising questions in the National People's Congress, in the Ministry of Finance, in policy circles, and in public discussions about the public administration of science and the management problems of government agencies. To its credit, MOST has responded quickly to recent cases of misconduct and has instituted a package of new evaluation and budgeting procedures intended to monitor research more closely and prevent and punish fraud and other forms of unethical scientific behavior.

The effective implementation of the MLP will require complex interministerial cooperation in the central government and intergovernmental cooperation between the central government and the provinces and cities, which are supposed to work out their own local plan for S&T development. To improve management at the central-government level, especially for the engineering megaprojects, MOST has proposed online systems for tracking the involvement of technical experts so as to avoid conflicts of interest, for monitoring the performance of researchers, and for facilitating funding applications.[8]

The ministry will seek to ensure its own continuing role in science policy and national research coordination, but the challenges of successfully implementing the MLP may engender a series of new administrative arrangements. It will be interesting to see if such a scenario comes to pass. In particular, members of the technical community have discussed the need to create a new supraministerial office of S&T policy. The office would improve interministerial coordination and provide science advice to government leaders who will face many new technical and institutional issues that arise as the plan is carried out. Quite conceivably, with the implementation of the MLP, pressures will grow for the creation of an administrative mechanism of this sort.

A grand experiment

Given its breadth and depth, the MLP is likely to have a major effect on Chinese S&T in the coming 15 years. At the very least, if China reaches its spending goals for R&D, it will have become a global scientific center. Of course, spending alone does not guarantee scientific distinction and technological prowess. The drafters of the MLP certainly recognize that point and have sought to encourage ongoing institutional and cultural change as a means to achieve the plan's goals.

For many observers inside and outside China, the MLP can be viewed as a grand experiment. It will be relevant to debates that have gone on in many countries for some time about the utility of state-directed programs of innovation versus decentralized, market-responsive approaches. Most students of innovation recognize a proper role for the state in promoting new knowledge and techniques, but determin-

Box 2. Areas and programs identified in China's 15-year science plan

Key areas

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

Frontier technology

Advanced energy
Advanced manufacturing
Aerospace and aeronautics
Biotechnology
Information
Laser
New materials
Ocean

Engineering megaprojects

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

Science megaprojects

Development and reproductive biology
Nanotechnology
Protein science
Quantum research

ing what is proper remains contentious and varies from country to country. Resolving the question requires mechanisms for assessing and evaluating the costs and benefits of state action. Market signals in China are beginning to help in those tasks, as is the increasing commitment to formal research evaluation. The growing concern expressed about government accountability is a promising development, but the lack of full, democratic accountability deprives China of an important source of information and feedback on the appropriateness of government S&T policies.

Another interesting question for which the MLP will provide insight is that of the proper balance between indigenous efforts at research and innovation on the one hand, and involvement with global technology flows and knowledge development on the other. Despite strong techno-nationalist themes in the discourse about the plan, it is inconceivable that Chinese S&T could have progressed to current levels without the productive engagement it has had during the past 25 years with foreign universities, research centers, and corporations. Chinese leaders appear to sense that the terms of this engagement may be changing. Nonetheless, they also seem to recognize that the globalization of research and innovation continues apace and that a country is unlikely to progress without involvement in it. Indeed, China's leaders have gone to great lengths to remind their foreign counterparts that the MLP is not designed to insulate China from international cooperation and significant participation in the world's emerging global knowledge system.

The implementation of the MLP also will help scholars and policymakers better understand the role of S&T in national development. China has a vast peasant population and, as of 2005, a per-capita GDP of only $1700; by those measures it remains a developing country. But by any number of indicators of scientific activity, it is not. China ranks fifth in international S&T publications, above France, Italy, and Canada. It has a relatively comprehensive S&T system, if not among the world's most advanced, with indigenous R&D in the life sciences, nanoscience, space technology, and other internationally important fields. Its pool of about 1 million scientists and engineers devoted to R&D is second only to the US, and China is about to surpass the US in the conferring of doctoral degrees in science and engineering. Such scientific resources encouraged the initiation of the MLP. It remains to be seen whether the plan can mobilize and organize China's resources in such a way as to accelerate economic and social development.

Notwithstanding the great promise of its S&T, China has daunting problems to overcome. In addition to those discussed here, there is the aging of China's population, which will affect the long-term supply of scientists and engineers and other professionals and will require the diversion of societal resources to support those who have become less productive. As with so many other aspects of Chinese life, such as the deteriorating environment, China is in a race to acquire the knowledge and wealth necessary to solve or ameliorate its problems before they become overwhelming. The MLP represents a strategy for winning that race and ensuring the country's long-term competitiveness in the face of the rapid and dramatic changes happening in the world of S&T.

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