The 'new normal' [of slower but steadier economic growth] highlights the urgency for China to transform its economic development model from one that is labour-, investment-, energy- and resource-intensive to one that is increasingly dependent upon technology and innovation.

Cong Cao

A high-speed train in Shanghai station in June 2013; the latest trains can clock a speed of up to 487 km/h in test conditions.
Photo © Anil Bolukbas/iStockPhoto

23 · China

Cong Cao

INTRODUCTION

The 'new normal'

China's socio-economic situation has evolved since 2009[1] in a climate of uncertainty caused first by the global financial crisis of 2008–2009 then by the domestic transtion in political leadership in 2012. In the immediate aftermath of the US subprime mortgage crisis in 2008, the Chinese government took swift action to limit the shockwaves by injecting RMB 4 trillion (US$ 576 billion) into the economy. Much of this investment targeted infrustructure projects such as airports, motorways and railroads. Combined with rapid urbanization, this spending spree on infrastructure drove up the production of steel, cement, glass and other 'building-block' industries, prompting concern at the potential for a hard landing. The construction boom further damaged China's environment. For example, outdoor air pollution alone contributed to 1.2 million premature deaths in China in 2010, nearly 40% of the world total (Lozano *et al.,* 2012). When China hosted the Asia–Pacific Economic Cooperation (APEC) summit in mid-November 2014, factories, offices and schools in Beijing and surrounding areas were all closed for several days to ensure blue skies over the capital for the duration of the summit.

The post-2008 economic stimulus package was also compromised by the failure of the government's policy to support the development of so-called strategic emerging industries. Some of these industries were export-oriented, including manufacturers of wind turbines and photovoltaic panels. They were hard hit by the slump in global demand during the global financial crisis but also by the anti-dumping and anti-subsidy measures introduced by some Western countries. The manufacturing glut that ensued bankrupted some of the global leaders in solar panel manufacturing, such as Suntech Power and LDK Solar, which were already ailing by the time the Chinese government cut back on its own subsidies in order to rationalize the market.

Despite these hiccups, China emerged triumphantly from the crisis, maintaining average annual growth of about 9% between 2008 and 2013. In terms of GDP, China overtook Japan in 2010 to become the world's second-largest economy and is now catching up with the USA. When it comes to GDP per capita, however, China remains an upper middle-income country. In a reflection of its growing role as an economic superpower, China is currently spearheading three major multilateral initiatives:

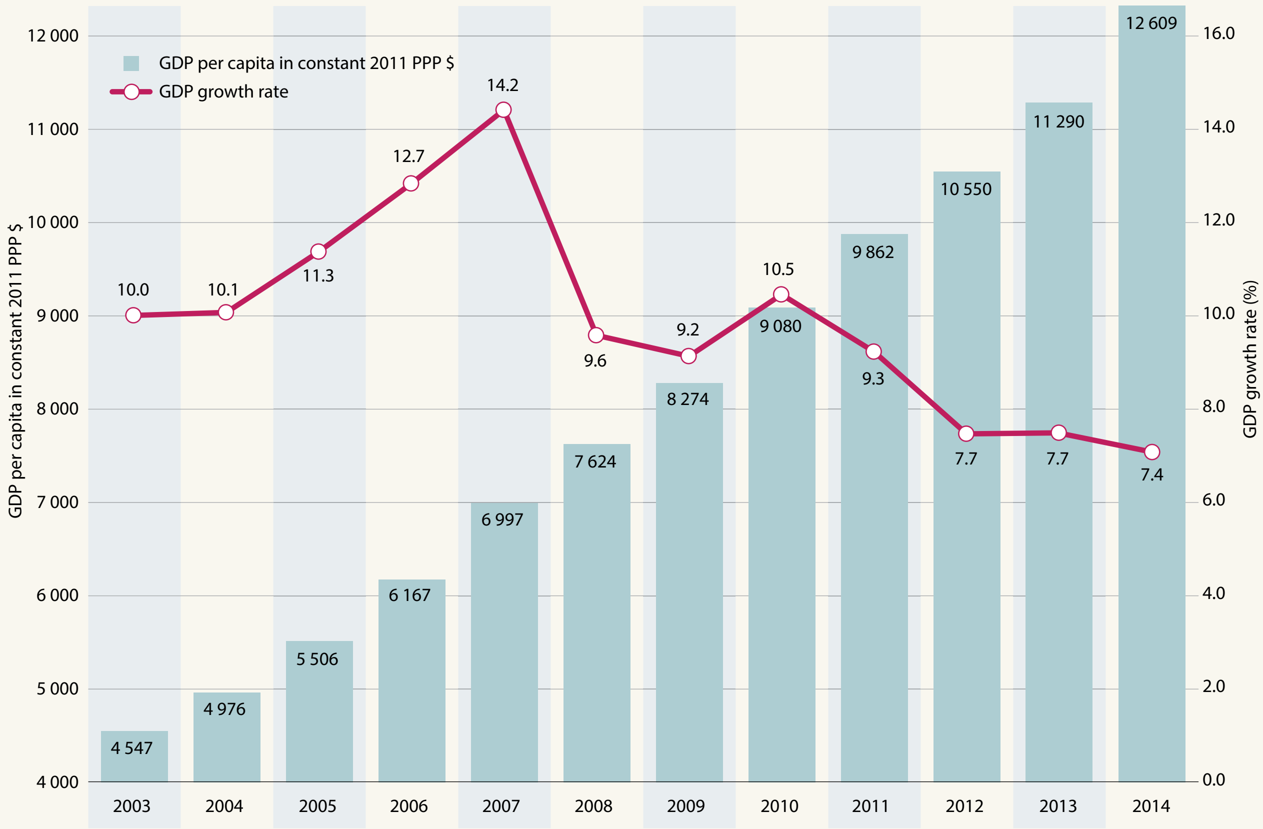
- the creation of the Asian Infrastructure Investment Bank to finance infrastructure projects, which will be based in Beijing and should be operational by the end of 2015; more than 50 countries have already expressed interest in joining, including France, Germany, the Republic of Korea and the UK;
- the approval by Brazil, the Russian Federation, India, China and South Africa (BRICS) in July 2014 of the New Development Bank (or BRICS Development Bank), with a primary focus on lending for infrastructure projects; it will be based in Shanghai; and
- the creation of an Asia–Pacific Free Trade Area, which, according to China's vision, would override existing bilateral and multilateral free trade agreements in the region; in November 2014, the APEC summit endorsed the Beijing Roadmap for completing a feasibility study by late 2016.

Meanwhile, China initiated a change in its political leadership in November 2012, when Xi Jinping acceded to the post of General Secretary of the Central Committee of the Chinese Communist Party (CCP) at the 18th CCP National Congress. At the first session of the 12th National People's Congress, held in March 2013, Xi Jinping and Li Keqiang took over the state presidency and premiership respectively. The Xi–Li administration inherited the legacy of an economy which had been growing at almost 10% on average for the past decade, as China vigorously pursued its open-door policy initiated by reformist leader Deng Xiaoping back in 1978. Today, China's economy seems to have reached a plateau, or a 'new normal' (*xin changtai*), characterized by steadier, albeit slower growth: GDP progressed by just 7.4% in 2014, the lowest rate in 24 years (Figure 23.1). China is gradually losing its status as 'the world's factory,' as rising costs and stringent environmental regulations make its manufacturing sector less competitive than in countries paying lower wages and offering less environmental protection. The 'new normal' therefore also highlights the urgency for China to transform its economic development model from one that is labour-, investment-, energy-, and resource-intensive into one that is increasingly dependent upon technology and innovation. The 'smart cities' initiative is one example of how the Chinese leadership is tackling this challenge (Box 23.1).

China faces other challenges which range from inclusive, harmonious and green development to an ageing society and the 'middle income trap.' All these call for the acceleration of the reform, which seems to have been delayed up until now by China's response to the global financial crisis. That may be about to change. The new leadership has put forward an ambitious and comprehensive reform agenda, in addition to launching an unprecedented anti-corruption campaign targeting some high-ranking government officials.

1. Total debt in China stood at about 210% of GDP by the end of 2014: household debt accounted for 34% of GDP, government debt 57% and corporate debt, including both loans and bonds, for 119%, according to the UNESCO Institute for Statistics.

Figure 23.1: **Trends in GDP per capita and GDP growth in China, 2003–2014**



Source: World Bank's World Development Indicators, March 2015

Box 23.1: **China's smart cities**

The 'smart city' takes its origin from the concept of 'smart planet' created by IBM. Today, the term 'smart cities' refers to futuristic urban centres where the use of information technology and data analysis improves infrastructure and public services so as to engage more effectively and actively with citizens. The development of smart cities takes advantage of synergic innovation around existing technologies cutting across many industries – transportation and utility infrastructure, telecommunications and wireless networks, electronic equipment and software applications, as well as emerging technologies such as ubiquitous computing (or the internet of things), cloud computing and 'big data' analytics. In a word, smart cities represent a new trend of industrialization, urbanization and informatization.

China is embracing the idea of smart cities to tackle challenges in government services, transportation, energy, environment, health care, public safety, food safety and logistics.

The *Twelfth Five-Year Plan* (2011–2015) specifically calls for the development of smart city technologies to be encouraged, thus stimulating the initiation of programmes and industrial alliances, such as the:

- China Strategic Alliance of Smart City Industrial Technology Innovation, managed by the Ministry of Science and Technology (MoST) since 2012;
- China Smart City Industry Alliance, managed by the Ministry of Industry and Information Technology (MoIIT) since 2013; and the
- Smart City Development Alliance, managed by the National Development and Reform Commission (NDRC) since 2014.

The most far-reaching effort has been led by the Ministry of Housing and Urban and Rural Development (MoHURD). By 2013, it had selected 193 cities and economic development zones to be official smart city pilot sites. The pilot cities are eligible for funding from a RMB 1 billion (US$ 16 billion) investment fund sponsored by the China Development Bank. In 2014, MoIIT also announced a RMB 50 billion fund to invest in smart city research and projects. Investment from local government and private sources has also been growing fast. It is estimated that total investment over the *Twelfth Five-Year Plan* period will reach some RMB 1.6 trillion (US$ 256 billion).

TRENDS IN R&D

The world's biggest R&D spender by 2019?

Over the past decade, China has been following a sharp uphill trajectory in science, technology and innovation (STI), at least in quantitative terms (Figures 23.2 and 23.3). The country has been spending a growing share of its burgeoning GDP on research and development (R&D). Gross domestic expenditure on R&D (GERD) stood at 2.08% in 2013, surpassing that of the 28-member European Union (EU), which managed an average intensity of 2.02% in 2013 (see Chapter 9). China's indicator nudged farther ahead to 2.09% of GDP in 2014. According to the biennial *Science, Technology and Industry Outlook 2014* (OECD, 2014), China will outpace the USA as the world's leading R&D spender by around 2019, reaching another important milestone in its endeavour to become an innovation-oriented nation by 2020. The policy focus on experimental development over the past 20 years, to the detriment of applied research and, above all, basic research, has resulted in enterprises contributing more than three-quarters of GERD. Since 2004, the bias in favour of experimental development has become even more pronounced (Figure 23.4).

China's S&T talent has been growing, with institutions of higher education turning out an increasing number of well-prepared graduates, especially in science and engineering. In 2013, the number of postgraduate students reached 1.85 million, on top of the 25.5 million undergraduates (Table 23.1). The number of researchers in China is unequivocally the world's highest: 1.48 million full-time equivalents (FTE) in 2013.

China's State Intellectual Property Office received more than half a million applications for invention patents in 2011, making it the world's largest patent office (Figure 23.5). There has also been a steady increase in the number of international papers by Chinese scientists in journals catalogued in the *Science Citation Index*. By 2014, China ranked second in the world after the USA, in terms of volume (Figure 23.6).

Some outstanding achievements

Chinese scientists and engineers have chalked up some outstanding achievements since 2011. In basic research, frontier discoveries include the quantum anomalous Hall effect, high-temperature superconductivity in iron-based materials, a new kind of neutrino oscillation, a method of inducing pluripotent stem cells and the crystal structure of the human glucose transporter GLUT1. In the area of strategic high technology, the Shenzhou space programme has pursued inhabited space flights. The first Chinese spacewalk dates from 2008. In 2012, the Tiangong-1 space module docked in space for the first time, allowing the first woman *taikongnaut* to go for a spacewalk. In December 2013, Chang'e 3 became the first spacecraft to land on the Moon since the Soviet Union's craft in 1976. China has also made breakthroughs in deep-ground drilling and supercomputing. China's first large passenger aircraft, the ARJ21-700 with a capacity for 95 passengers, was certified by the national Civil Aviation Administration on 30 December 2014.

Given such an attraction, a growing number of Chinese citizens will be clamouring for their city to climb on the 'smart city' bandwagon.

In early 2014, the ministries involved in the smart city initiative joined forces with the Standardization Administration of China to create working groups entrusted with managing and standardizing smart city development.

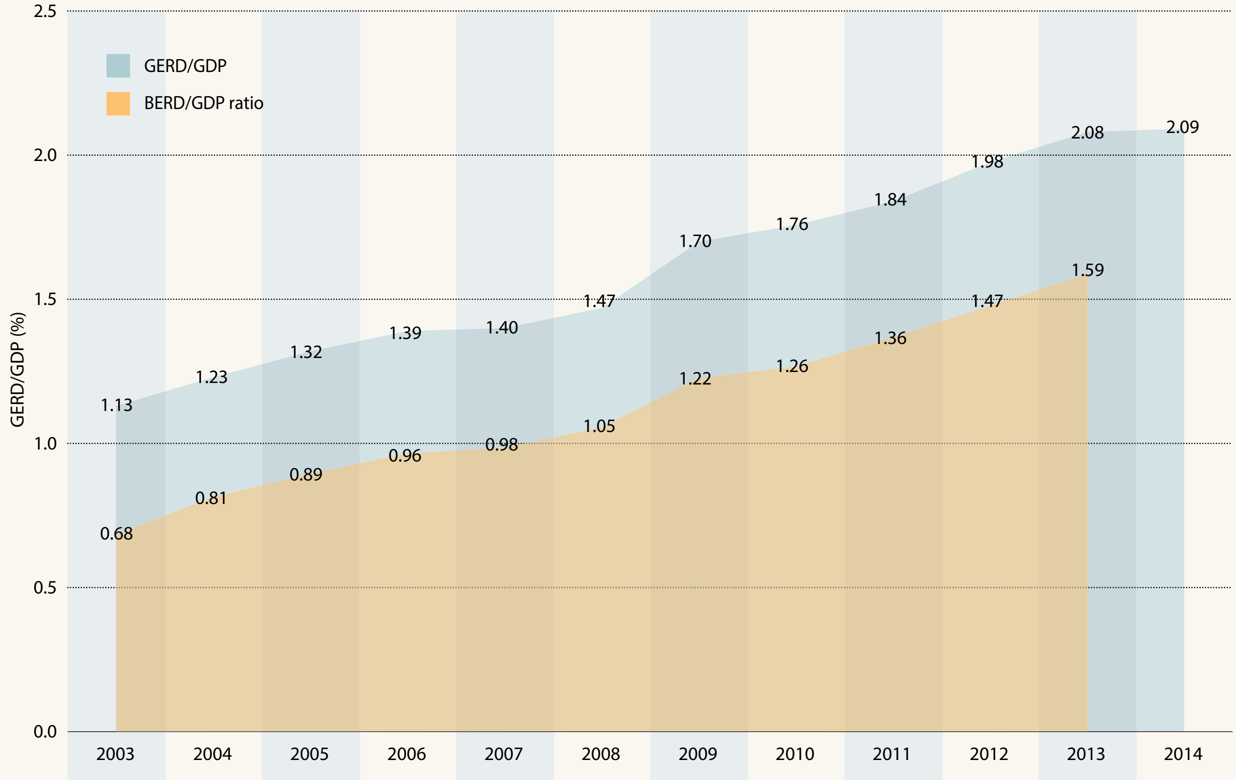
Apparently, it is the smart city boom which drove eight government agencies to issue a joint guide in August 2014, in order to improve co-ordination and communication between industrial participants and between industry and government agencies, entitled *Guidance on Promoting the Healthy Development of Smart Cities.* The document proposed establishing a number of smart cities with distinctive characteristics by 2020 to lead the development of smart cities across the country. The eight government agencies were the NDRC and seven ministries: MoIIT, MoST, Public Security, Finance, Land Resources, MoHURD and Transportation.

Companies such as IBM have not only used the smart city concept as their marketing strategy but also seized upon the opportunity to develop their businesses in China. As early as 2009, IBM launched a 'smart city' programme in the northeastern city of Shenyang in Liaoning province, hoping to showcase its strengths. It has also worked with Shanghai, Guangzhou, Wuhan, Nanjing, Wuxi and other cities on their own smart city initiatives. In 2013, IBM set up its first Smart Cities Institute in Beijing as an open platform for experts from the company, as well as its partners, clients, universities and other research institutions to work on joint projects related to smart water resources, smart transportation, smart energy and smart new cities.

Chinese firms that have also been adept at mastering technologies and shaking up markets include Huawei and ZTE, both telecommunications equipment manufacturers, as well as China's two electric grid companies, State Grid and Southern Grid.

Source: www.chinabusinessreview.com

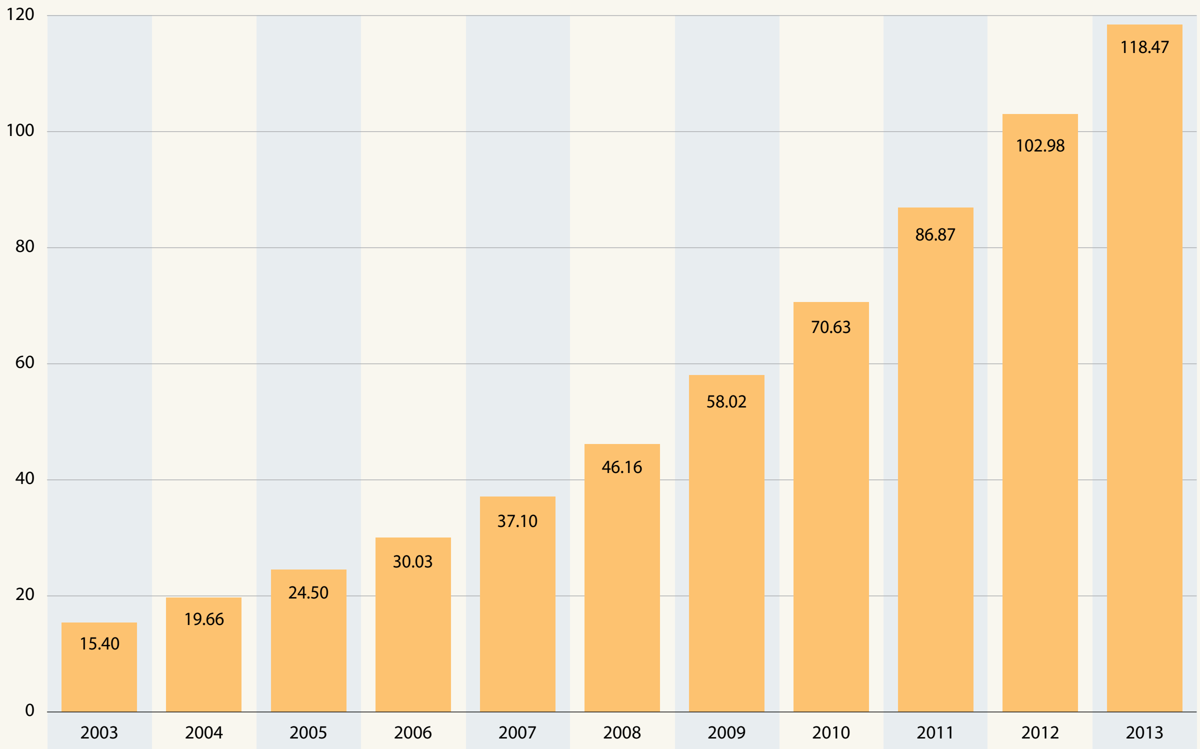
Figure 23.2: **Chinese GERD/GDP ratio and BERD/GDP ratio, 2003–2014 (%)**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

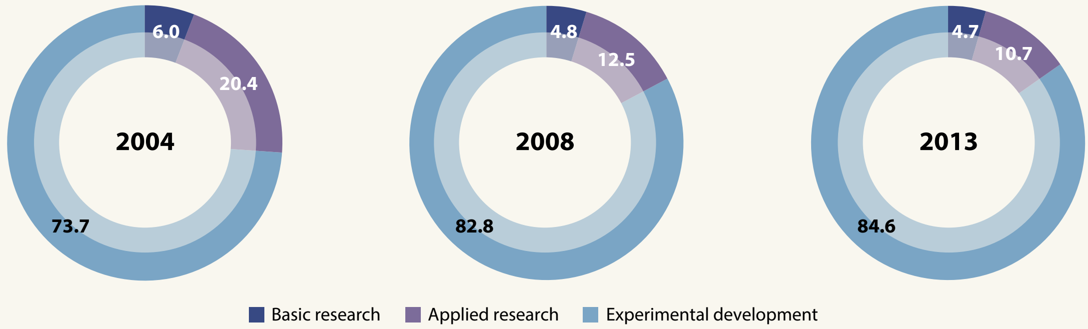
Figure 23.3: **Growth in Chinese GERD, 2003 –2013**

In RMB 10 billions



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

Figure 23.4: **GERD in China by type of research, 2004, 2008 and 2013 (%)**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

Table 23.1: **Trends in Chinese human resources in S&T, 2003–2013**

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
FTE research personnel ('000s)	1 095	1 153	1 365	1 503	1 736	1 965	2 291	2 554	2 883	3 247	3 533
FTE research personnel per million inhabitants	847	887	1 044	1 143	1 314	1 480	1 717	1 905	2 140	2 398	2 596
Graduate student enrolment ('000s)	651	820	979	1 105	1 195	1 283	1 405	1 538	1 646	1 720	1 794
Graduate student enrolment per million inhabitants	504	631	749	841	904	966	1 053	1 147	1 222	1 270	1 318
Undergraduate student enrolment (millions)	11.09	13.33	15.62	17.39	18.85	20.21	21.45	22.32	23.08	23.91	24.68
Undergraduate student enrolment per million inhabitants	8 582	10 255	11 946	13 230	14 266	15 218	16 073	16 645	17 130	17 658	18 137

Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

A number of major gaps in technology and equipment have been filled in recent years, especially in information and communication technologies (ICTs),[2] energy, environmental protection, advanced manufacturing, biotechnology and other strategic emerging industries for China.[3] Large facilities such as the Beijing Electron-Positron Collider (est. 1991), Shanghai Synchrotron Radiation Facility (est. 2009) and Daya Bay neutrino oscillation facility have not only yielded significant findings in basic science but also provided opportunities for international collaboration. The Daya Bay Neutrino Experiment, for example, which began collecting data in 2011, is being led by Chinese and American scientists, with participants from the Russian Federation and other countries.

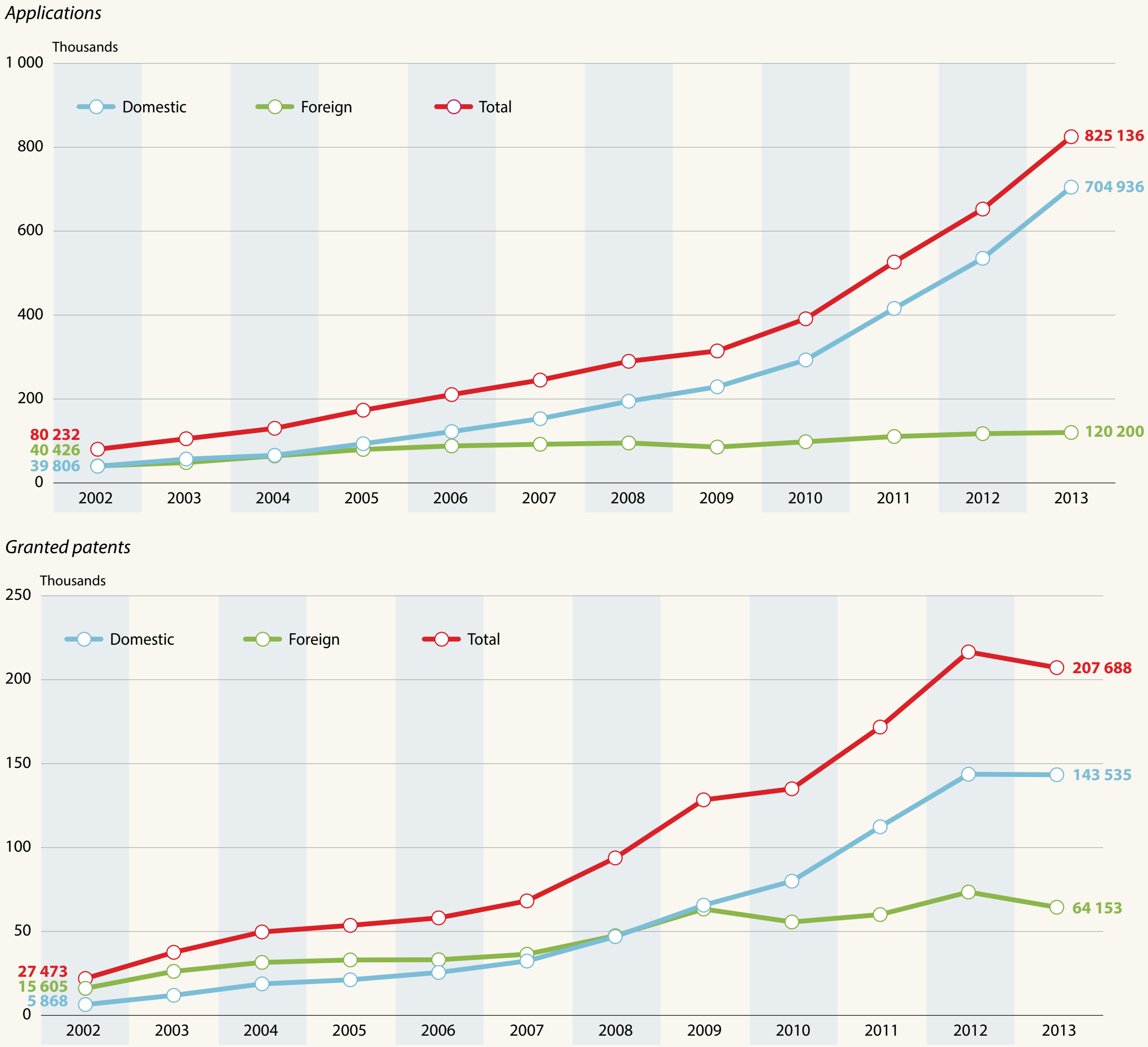
A leap forward in medical sciences

China has made leaps and bounds in medical sciences in the past decade. Publications in this field more than tripled between 2008 and 2014 from 8 700 to 29 295, according to the Web of Science. This progression has been much faster than in China's traditional strengths of materials science, chemistry and physics. According to the Institute of Scientific and Technical Information of China, which is affiliated with the Ministry of Science and Technology (MoST), China contributed about one-quarter of all articles published in materials science and chemistry and 17% of those published in physics between 2004 and 2014 but just 8.7% of those in molecular biology and genetics. This nevertheless represents a steep rise from just 1.4% of the world share of publications in molecular biology and genetics over 1999–2003. In the early 1950s, Chinese research in genetics came to a standstill after the country officially adopted Lysenkoism, a doctrine developed by Russian peasant plant-breeder Trofim Denisovich Lysenko (1898–1976) which had already stalled genetic research in the Soviet Union. Essentially, Lysenkoism dictated that we are what we learn. This environmentalism denied the role played by genetic inheritance in evolution. Although Lysenkoism was discarded in the late 1950s, it has taken Chinese geneticists decades to catch up (UNESCO, 2012). China's participation in the Human Genome Project at the turn of the century was a turning point. More recently, China has thrown its support behind the Human Variome Project, an international endeavour to catalogue human genetic variation worldwide, in order to improve diagnosis and treatment, with support

2. 649 million Chinese inhabitants had access to internet by the end of 2014.

3. China defines strategic emerging industries as: energy-saving and environment-friendly technologies, new generation ICTs, biotechnology, advanced manufacturing, new energy, new materials and automobiles powered by new energy sources.

Figure 23.5: **Applications and patents granted to Chinese and foreign inventors, 2002–2013**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

from UNESCO's International Basic Sciences Programme. In 2015, the Beijing China Health Huayang Institute of Gene Technology committed *circa* US$ 300 million to the Human Variome Project; the funds will be used over the next ten years to build 5 000 new gene- and disease-specific databases and to establish the Chinese node of the Human Variome Project.

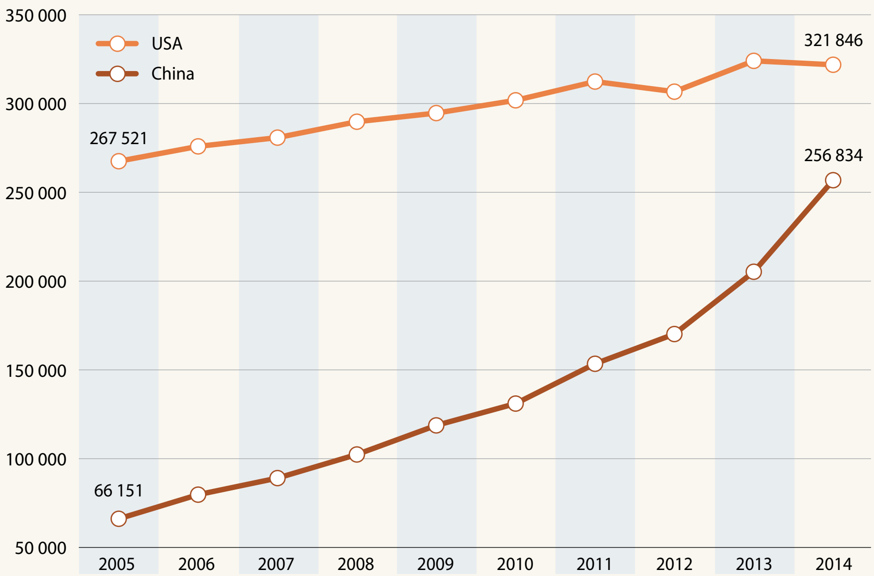
Two new regional centres for training and research

Other opportunities for international collaboration have arisen from the establishment of two regional centres for research and training since 2011, which function under the auspices of UNESCO:

- the Regional Training and Research Centre on Ocean Dynamics and Climate was launched on 9 June 2011 in Qingdao City. It is hosted by the First Institute of Oceanography, part of the State Oceanic Administration, and trains young scientists from Asian developing countries, in particular, at no cost to the beneficiary;
- the International Research and Training Centre for Science and Technology Strategy was inaugurated in Beijing in September 2012. It designs and conducts international co-operative research and training programmes in such areas as S&T indicators and statistical analysis, technology foresight and road-mapping, financing policies for innovation, the development of small and medium-sized enterprises, strategies for addressing climate change and sustainable development, etc.

Figure 23.6: **Scientific publication trends in China, 2005–2014**

China could become world's largest scientific publisher by 2016



0.98

Average citation rate for Chinese scientific publications, 2008–2012; the OECD average is 1.08; the G20 average is 1.02

10.0%

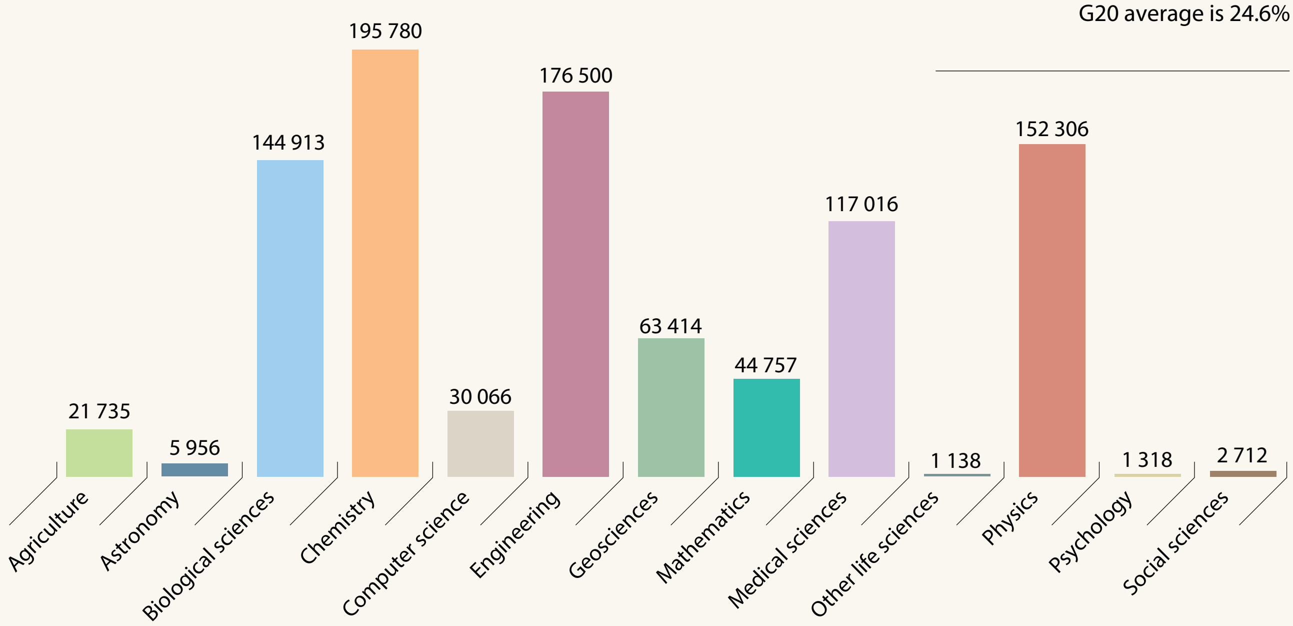
Share of Chinese papers among 10% most cited, 2008–2012; the OECD average is 11.1%; the G20 average is 10.2%

24.4%

Share of Chinese papers with foreign co-authors, 2008–2014; the OECD average is 29.4%; the G20 average is 24.6%

Chemistry, engineering and physics dominate Chinese science

Cumulative totals by field 2008–2014



Note: The totals exclude 180 271 unclassified publications.

The USA outstrips all others as China's main partner

Main foreign partners 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
China	USA (119 594)	Japan (26 053)	UK (25 151)	Australia (21 058)	Canada (19 522)

Note: The statistics for China do not include Hong Kong SAR or Macao SAR.

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

TRENDS IN STI GOVERNANCE

Reform driven by engineers turned politicians

China's astonishing progress in STI can be attributed to a series of policies adopted during the reformist open-door era since 1978, from 'rejuvenating the nation with science, technology and education' (*kejiao xingguo*), in 1995, 'empowering the nation with talent' (*rencai qiangguo*), in 2001, and 'building up an endogenous innovation capability' (*zizhu chuangxin nengli*) to 'turning China into an innovation-oriented nation' (*chuangxin guojia*) in 2006, a strategy ensconced in the *National Medium and Long-term Plan for the Development of Science and Technology (2006–2020)*. The Chinese power structure in the 1980s and 1990s could be described as an alliance between career bureaucrats and technocrats; the bureaucrats needed the technocrats to modernize and develop the economy, whereas the technocrats needed the bureaucrats to advance their political careers. Following Deng's death in 1997, Jiang Zemin became China's 'top technocrat' and instigated a fully-fledged technocracy (Yoon, 2007). Given their training at the nation's top science and engineering schools, China's governing political elite was naturally inclined to favour policies that promoted advances in science and technology (Suttmeier, 2007). Only in its current top leadership did China start to see the rise of social scientists: Xi Jinping holds a PhD in Law from Tsinghua University and Li Keqiang obtained his PhD in Economics from Beijing University. However, the change in educational background of the current leadership does not mean that attitudes towards science and technology have changed among these top leaders.

In July 2013, soon after being made General Secretary of the Chinese Communist Party's (CCP's) Central Committee and State President, Xi Jinping paid a visit to the Chinese Academy of Sciences (CAS), the nation's leading institution for science and research. His articulation of the problems facing the development of science and technology in China was distilled into 'four mismatches' (*sige buxiang shiying*): mismatches between the level of technological development and the requirements of socio-economic development; between the S&T system and the requirements of science and technology for the system to develop rapidly; between the distribution of S&T disciplines and the requirements of science and technology for these disciplines to develop; and between existing S&T personnel and the requirements of the nation in terms of talent. Xi then urged CAS to be 'a pioneer in four areas' (*sige shuaixian*): in leapfrogging to the frontier of scientific research, in enhancing the nation's innovative talent pool, in establishing the nation's high-level think tank in science and technology and in becoming a world-class research institution.

China's political leadership is also enthusiastic about broadening its knowledge. This is illustrated by the fact that, since 2002, the Politburo of the CCP's Central Committee has held frequent group study sessions, to which leading Chinese scholars have been invited to lecture on subjects related to China's socio-economic development, including STI. The Xi–Li duo has pursued this tradition. In September 2013, the Politburo held a group study at Beijing's Zhongguancun Science Park, also known as China's 'Silicon Valley.' During this ninth group study session run by the new leadership – the first ever held outside the Communist Party's Zhongnanhai headquarters – members of the Politburo showed particular interest in new technologies such as three-dimensional printing, big data and cloud computing, nano-materials, biochips and quantum communications. While stressing the importance of science and technology in enhancing the nation's strength, in the speech he gave for the occasion, Xi Jinping indicated that China should focus on integrating innovation with socio-economic development, enhancing the capability for endogenous innovation, nurturing talent, constructing a favourable policy environment for innovation and continuing to open up and engage in international co-operation in science and technology. Calls from the leadership since 2013 for 'positive energy' (*zheng nengliang*) to prevail in all spheres of society, including the university sector, have raised concerns, however, that this new doctrine may inhibit the critical thinking which nurtures creativity and problem-solving research, if the evocation of problems comes to be assimilated with 'negative energy.'

The new leadership is focusing on weaving together the so-called 'two layers of skin' (*liang zhang pi*) of research and the economy, a long-lasting challenge for China's S&T system. The main topic of discussion at the seventh meeting of the Central Leading Group for Financial and Economic Affairs on 18 August 2014, chaired by Xi Jinping, was a draft innovation-driven development strategy which was formally released by the CCP Central Committee and State Council on 13 March 2015. This, in itself, reflects the importance that the leadership attaches to innovation for restructuring China's economic development model.

Enterprises still dependent on foreign core technologies

In fact, the attention being paid to STI at the moment by the political leadership stems from its dissatisfaction with the current performance of the domestic innovation system. There exists a mismatch between input and output (Simon, 2010). Despite a massive injection of funds (Figure 23.3), better-trained researchers and sophisticated equipment, Chinese scientists have yet to produce cutting-edge breakthroughs worthy of a Nobel Prize, including the returnees who are now firmly embedded in domestic research and innovation (Box 23.2). Few research results have been turned into innovative and competitive technology and products. The commercialization of public research results has been rendered difficult, if not impossible, by the fact that these results are considered public goods, thus disincentivizing researchers engaged in technology transfer. With few exceptions, Chinese enterprises still depend on foreign sources for core technologies. According to a World Bank study, China had a US$ 10 billion deficit in 2009 in its intellectual property balance of payments, based on royalties and license fees (Ghafele and Gibert, 2012).

These problems have forced China to put its ambition on hold of embarking on a truly innovation-driven development trajectory. Indeed, China's drive to become a global leader in STI is tied to its capacity to evolve towards a more efficient, effective and robust national innovation system. Upon closer examination, there is a lack of co-ordination between the various actors at the macro level, an unfair distribution of funding at the meso level and an inappropriate performance evaluation of research projects and programmes, individual scientists and institutions at the micro level. It would seem to be both urgent and inevitable to institute reforms across all three levels of the national innovation system (Cao *et al.*, 2013).

Reform has accelerated under the new leadership

The current reform of the country's science and technology system was initiated against such a backdrop. It got under way in early July 2012, when a National Conference on Science, Technology and Innovation was convened shortly before the transition in leadership. One key outcome of the conference was an official document, *Opinions on Deepening the Reform of the Science and Technology System and Accelerating the Construction of the National Innovation System*, released in September. Produced by the CCP's Central Committee and State Council, this document furthered implementation of the *National Medium- and Long-Term Plan for the Development of Science and Technology (2006–2020),* which was released in 2006.

It was also in September 2012 that a new State Leading Group of Science and Technology System Reform and Innovation System Construction convened its first meeting. Made up of representatives from 26 government agencies and headed by Liu Yandong, a member of the Central Committee Politburo and state councillor, the leading group is mandated to guide and co-ordinate the reform and the construction of China's national innovation system, in addition to discussing and approving key regulations. When the country's top leadership changed a few months later, Liu not only kept her party position but was also promoted to vice premier in the state apparatus, thereby ensuring continuity and confirming the importance attached to scientific affairs.

The reform of the S&T system has accelerated since the change in political leadership. In general, the reform conducted by the Xi–Li tandem is characterized by so-called 'top-level design' (*dingceng sheji*), or strategic considerations in formulating the guidelines, so as to ensure that the reform is comprehensive, co-ordinated and sustainable; a balanced and focused approach towards reform which takes into consideration the interests of the CCP and country; and a focus on overcoming institutional and structural barriers, not to mention deep-seated contradictions, while promoting co-ordinated innovation in economic, political, cultural, social and other institutions. Of course, the 'top-level design' has been more broadly exercised in the reforms under the Xi–Li administration. In particular, the reform of the S&T system has strong political backing, with Xi Jinping's aforementioned visit to CAS and the Politburo's Zhongguancun group study setting the course. On several occasions, Xi has taken time off from his busy schedule to preside over the presentation of reports by the relevant government agencies on progress with the reform and the innovation-driven development strategy. He has also been very hands-on when it comes to the reform of China's elite academician (*yuanshi*) system at CAS and the Chinese Academy of Engineering (CAE), the broader reform of CAS and that of funding mechanisms for the centrally financed national science and technology programmes (see p. 633).

A mid-term review of the *Medium- and Long-Term Plan*

In addition to the political leadership's concerns about the mismatch between the soar in R&D input and the relatively modest output in science and technology, coupled with the necessity of harnessing science and technology to restructuring China's economy, the desire for reform may have been spurred by the mid-term review of the *National Medium and Long-term Plan for the Development of Science and Technology (2006–2020)*. As we saw in the *UNESCO Science Report 2010*, the *Medium- and Long-term Plan* set several quantitative goals for China to achieve by 2020, including (Cao *et al.,* 2006):

- raising investment in R&D to 2.5% of GDP;
- raising the contribution of technological advances to economic growth to more than 60%;
- limiting China's dependence on imported technology to no more than 30%;
- becoming one of the top five countries in the world for the number of invention patents granted to its own citizens; and
- ensuring that Chinese-authored scientific papers figure among the world's most cited.

China is well on the way to reaching these quantitative goals. As we have seen, by 2014, GERD had reached 2.09% of GDP. Moreover, technological advances are already contributing more than 50% to economic growth: in 2013, Chinese inventors were granted some 143 000 invention patents and China had risen to fourth place worldwide for the number of citations of Chinese-authored scientific papers. China's dependence on foreign technology should drop to about 35% by 2015. Meanwhile, various government ministries have worked together to initiate policies designed to facilitate implementation of the *Medium- and Long-Term Plan*. These policies include providing innovative enterprises with tax incentives and other forms of financial support, prioritizing domestic high-tech enterprises for government procurement, encouraging assimilation and re-innovation based on imported technology, strengthening the protection of intellectual property rights, nurturing talent, enhancing education and science popularization and establishing the basic platform of S&T innovation (Liu, *et al.,* 2011).

This begs the question: if we look beyond the statistics, what impact has the *Medium- and Long-Term Plan* had on realizing China's ambition of becoming an innovation-oriented nation by 2020? The mid-term review of the *Medium- and Long-Term Plan*'s implementation was approved by the State Council in November 2013. The Ministry of Science and Technology led this effort, assisted by a steering committee set up in conjunction with 22 government agencies, the Chinese Academy of Engineering having been commissioned to organize the review. The same 20 thematic groups which had conducted strategic research at the stage of drafting the *Medium- and Long-Term Plan* now consulted experts from CAS, CAE and the Chinese Academy of Social Sciences. Consultations at CAS alone involved more than 200 experts. Focus groups were constituted with personnel from innovative enterprises, multinational companies operating in China, R&D institutes, universities and other sectors. Attention was paid to measuring the progress made by the 16 mega-engineering programmes (Table 23.2), as well as cutting-edge basic research conducted in a number of key areas through mega-science programmes, the reform of the S&T system, the construction of an enterprise-centered national innovation system, the policies formulated to support implementation of the *Medium- and Long-Term Plan* and so on. Through expert interviews and consultations, as well as questionnaires, the review team also solicited the views of international experts and scholars on China's evolving capability for

Box 23.2: **Wooing the Chinese elite back home**

Since the introduction of the open-door policy, China has sent more than 3 million students overseas. Of these, about 1.5 million have returned (Figure 23.7). Among the returnees figure a growing number of seasoned entrepreneurs and professionals who have taken advantage of the vast opportunities created by China's rapid economic growth and the preferential policies implemented by the Chinese government to woo them.

Since the mid-1990s, high-profile programmes have been rolled out by the Ministry of Education (Cheung Kong Scholar Programme), the Chinese Academy of Sciences (One Hundred Talents Programme) and other central and local government agencies. These talent-focused programmes have dangled extremely generous incentives, resources and honours before potential recruits. They have targeted scientific pioneers, leaders in key technologies and corporate managers from high-tech industries but also – especially during the global financial crisis – professionals from consulting and the financial and legal worlds. However, these programmes have failed to persuade expatriate Chinese occupying the top jobs to return home.

Unhappy about the overall progress in STI and higher education despite an avalanche of funds, China's political leadership has attributed the problem to the lack of talent of the calibre of the father of China's space technology, Qian Xuesen, or the founder of geomechanics, Li Siguang, or of nuclear physicist Deng Jiaxian. In late 2008, the Department of Organization of the CCP's Central Committee, which appoints and evaluates senior officials at the provincial and ministerial levels, added the title of 'headhunter' to its curriculum vitae by initiating the Thousand Talents Programme *(qianren jihua)*.

In essence, the Thousand Talents Programme aims to spend 5–10 years wooing some 2 000 expatriate Chinese under the age of 55 who hold a foreign doctoral degree and are full professors at well-known institutions of learning, experienced corporate executives and entrepreneurs with patents for core technologies under their belt. The state has agreed to give each recruit RMB 1 million as a start-up subsidy. In parallel, the host institution or enterprise will provide housing of 150–200 m^2 and a salary to match that earned overseas, or almost; a national title is also bestowed upon the recruit.

In late 2010, a new component was added to the Thousand Talents Programme, targeting aspiring young scientists and engineers aged 40 years and under who hold a doctorate from a well-known foreign university, have at least three years of overseas research experience and hold a formal appointment at a well-known foreign university, research institute or company. The recruit is required to work full-time at a Chinese institution for an initial period of five years. In return, he or she receives a subsidy of RMB 500 000 and a research grant worth RMB 1–3 million.

By 2015, the programme had signed up some 4 100 Chinese expatriates and foreign experts with impeccable credentials. Wang Xiaodong, a prestigious Howard Hughes Medical Institute investigator who was elected

Table 23.2: **China's mega-engineering programmes to 2020**

The 16 mega-engineering programmes correspond to about 167 smaller projects. Thirteen have been made public.

Advanced manufacturing technology	Extra large-scale integrated circuit manufacturing technology and associated technology
	Advanced computerized numerical control machinery and basic manufacturing technology
Transportation	Large aircraft
Agriculture	Cultivation of new varieties of genetically modified organisms (Box 23.3)
Environment	Water pollution control and governance (Box 23.4)
Energy	Large-scale oil and gas fields and coal-bed methane development
	Advanced large-scale pressurized water reactors and nuclear power plants with high-temperature, gas-cooled reactors (Box 23.5)
Health	Development of significant new drugs
	Prevention and treatment of AIDS, viral hepatitis and other major infectious diseases
ICTs	Core electronic devices, high-end generic chips and basic software
	Next-generation broadband wireless mobile communication
Space technologies	High-resolution Earth observation system
	Human space flight and the Moon exploration programme

Source: National Medium- and Long-term Plan for the Development of Science and Technology (2006–2020)

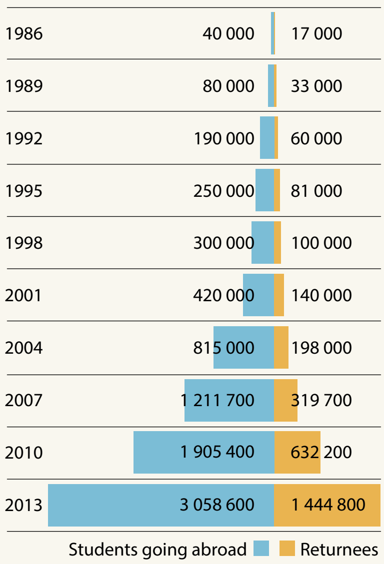
to the US National Academy of Sciences in 2004 at the tender age of 41, and Shi Yigong, a chair professor of structural biology at Princeton University, figure among the prize catches.

The Thousand Talents Programme is not flawless, be it in design or implementation. For one thing, the criteria have changed over time. The programme originally targeted full professors at well-known foreign universities or their equivalents; in practice, the threshold has been lowered to full professors from any institution or even associate professors. Preferential treatment that was originally reserved for new recruits has been extended to qualified earlier returnees with retrospective effect. The evaluation of candidates has paid most attention to academic publications and the required length of full-time employment has been reduced to six months. Given that many, if not most, of the recruits only spend a couple of months in China, even though their contract usually specifies otherwise, the Department of Organization has had to introduce a short-term two-month employment scheme. This not only significantly departs from the programme's original goal but also casts doubt as to whether the programme will encourage the permanent return of outstanding expatriates. This setback suggests that high-flying expatriate Chinese still don't feel the environment is ready for making their move permanent, despite a generous pay package. Among the reasons for this reluctance: personal relationships (*guanxi*) often override considerations of merit in China when it comes to reviewing grant proposals, promotion and awards; rampant misconduct has also tainted the Chinese scientific community; and, in social sciences, some research areas remain taboo.

The Department of Organization has never published the formal list of beneficiaries, for fear that recruits might be frowned upon by their foreign employers or even lose their position through a conflict of interest.

The programme has also alienated domestically trained talent, whose training has been perceived as being of inferior quality, and early returnees, who were treated less generously than more recent recruits. In order to correct these failings, the Department of Organization launched a Ten Thousand Talents Programme, in August 2012 which offers similar perks to a wider range of hopefuls.

Figure 23.7: **Cumulative number of Chinese students going abroad and returnees, 1986–2013**



Source: Author's research

endogenous innovation in a constantly mutating international environment. The mid-term review also included an exercise in which more than 8 000 domestic and foreign experts were invited to assess China's mega-engineering programmes, including through technology foresight studies, to determine where China stood in these technological areas (Table 23.2). Beijing, Jiangsu, Hubei, Sichuan, Liaoning and Qingdao were all selected as sites for the mid-term review at the provincial and municipal levels.

The review was originally due for completion by March 2014 and its preliminary findings were scheduled for distribution to the public by the end of June the same year. However, the second meeting of the steering committee was only held on 11 July 2014. Once the assessment has been completed, the review team will summarize the information collected on the *Medium- and Long-Term Plan's* implementation thus far and the role that science and technology have played since 2006 in driving socio-economic development. Recommendations will then be made for adjusting the implementation plan accordingly. The outcome of the review will also feed into the formulation of the *Thirteenth Five-Year Plan* (2016–2020) and the launch of the S&T systemic reform.

It would nevertheless appear that the review of the *Medium- and Long-Term Plan* will re-affirm the so-called 'whole nation system' (*juguo tizhi*) approach, by which the nation's resources are channelled towards select prioritized areas.[4] This approach is reminiscent of the state-led development of China's strategic weapons programmes (*liangdan yixing*) from the mid-1960s onwards through resource concentration and mobilization. Along with the introduction of 'top-level design' into the formulation of reform initiatives, it may become a hallmark of innovation in China in the years to come.

4. This approach originated from China's state-run sports system, or 'whole nation system' where it was the practice to concentrate the entire nation's resources on the training of athletes who showed promise for winning China medals at the Olympic Games. The success of China's strategic weapons programmes in the 1960s and 1970s and subsequent national defence programmes has been attributed to such a metaphor, which is also used to describe the 16 mega-engineering programmes launched under the *Medium- and Long-Term Plan* to 2020.

Box 23.3: **Cultivating a new variety of GMOs: a mega-engineering programme**

This programme was officially launched on 9 July 2008 when the State Council gave it the go-ahead after debating whether China should commercialize particular genetically modified organisms (GMOs) and, if so, when, as well as how to establish a stringent biosafety and risk assessment mechanism. This is arguably the most controversial of the 16 mega-engineering programmes.

Run by the Ministry of Agriculture, the programme aims to obtain genes with far-reaching applicability and indigenous intellectual property rights and to cultivate major new GMO varieties with traits for disease and insect resistance, stress tolerance and high yields, to promote efficient agricultural production, raise the overall level of agricultural transgenic technology and commercialization and underpin the sustainable development of Chinese agriculture with strong scientific support. Between 2009 and 2013, the central government's appropriation to the programme totalled RMB 5.8 billion.

Current work includes developing GM crops with resistance to virus, diseases, insects, bacteria and fungi, as well as tolerance to weed-killing herbicides. GM crops such as wheat, maize, soybean, potato, canola, peanut and others are at different stages of laboratory studies, field trials or environmental release but have not yet reached the stage of biosafety certification permitting commercialization.

In the past couple of years, China has witnessed a change in policy towards transgenic technology and especially GM crops, which coincided with the change in the political leadership in late 2012 and early 2013. China's position on the issue of transgenic plants was elaborated in Xi Jinping's speech at the central conference on rural work on 23 December 2013. He said that it is quite normal for there to be doubts and debate, as transgenic plants use a novel technology but that it has broad prospects for development. Xi emphasized the importance of strictly following technical regulations and specifications formulated by the state, proceeding steadily to ensure no mishap and taking safety into account. He also indicated that China should boldly carry out research and innovation, take the commanding heights of transgenic technology and not allow foreign companies to occupy China's market for agricultural GM products.

Soon after the programme's inception, the long-delayed biosafety certification process for GM crops was accelerated to allow biosafety certificates to be issued for two strains of GM rice and phytase maize in 2009. These biosafety certificates expired in August 2014, amid rising contestation from anti-GMO activists. The certificates were nevertheless renewed on 11 December 2014. It remains to be seen whether the GMO mega-engineering programme will proceed smoothly over the next five years.

Source: www.agrogene.cn; author's research

Reform of the Chinese Academy of Sciences

The latest reform of CAS once again raises the question of the academy's place in China's national S&T system, a question which first came up at the academy's inception immediately after the founding of the People's Republic of China in 1949. At the time, research and training were separated at universities and industrial R&D institutes focused on specific problems in their particular sectors. These were the glory days of the academy, when it contributed, in particular, to the success of the strategic weapons programmes through a mission-oriented disciplinary development strategy.

CAS would quickly become a victim of its own success, after its high visibility attracted keen attention from the political leadership and other actors in the S&T system. In the mid-1980s when China began reforming its S&T system, CAS was forced to adopt a 'one academy, two systems' approach. This strategy consisted in concentrating a small number of scientists on basic research and following the global trend in high technology, while encouraging the majority of its staff to engage in the commercialization of research results and projects of direct relevance to the economy. The overall quality of research suffered, as did the academy's ability to tackle fundamental research questions.

In 1998, the president of CAS, Lu Yongxiang, initiated the Knowledge Innovation Programme to improve the academy's vitality (Suttmeier *et al.*, 2006a; 2006b). Initially, CAS hoped to satisfy the Chinese leadership by making the staff of its institutes more nimble and mobile. The academy's very existence was threatened, however, after it was downsized to compensate for the government's efforts to strengthen the research capability of universities and the national defence sector – ironically, the very sector that had historically absorbed CAS personnel or depended upon CAS to take on major research projects. In reaction, CAS not only reversed its early approach but even went to the other extreme by significantly expanding its reach. It established application-focused research institutes in new scientific disciplines and new cities and formed alliances with provincial and local governments and industries. The Suzhou Institute of Nanotech and Nanobionics is one such establishment; it was created jointly by CAS and the Jiangsu provincial and Suzhou municipal governments in 2008. Apparently, some of these new institutes are not fully supported by the public purse; in order to survive, they have to compete with existing institutes and engage in activities that bear little relation to CAS's mission as the national academy. Although CAS hosts the world's largest graduate school in terms of the number of postgraduate degrees awarded each year, which include 5 000 PhDs, CAS has been finding it difficult in recent years to attract the best and brightest students. This has spurred CAS to found two affiliated universities in Beijing and Shanghai, both of which opened their doors to a couple of hundred undergraduates in 2014.

CAS: full of promise but overstretched

Today, CAS employs a staff of 60 000 and counts 104 research institutes. It operates on a budget of roughly RMB 42 billion (*circa* US$ 6.8 billion), just under half of which comes from the government. The academy is struggling with a number of challenges. For one thing, it is in direct competition with other Chinese institutions of learning for funding and talent. Underpaid CAS scientists also have to apply constantly for grants to supplement their income, a widespread phenomenon in the entire research and higher education sector, which may have resulted in underperformance. CAS has also seen its work duplicated on a large scale by its own institutes, which tend not to collaborate with each other. There is also a lack of interest among CAS scientists in seeking opportunities to apply their research to the economy, although this should not be its core mission. Last but not least, the academy is encumbered by the breadth of its mandate, which ranges from research, talent training, strategic high-tech development, commercialization of research results and local engagement to the provision of policy advice as a think tank and through its elite academicians; this makes it extremely difficult for CAS to manage and evaluate institutes and individual scientists. In a word, the academy is big and full of promise, yet so cumbersome, weighed down by the legacy of the past (Cyranoski, 2014a).

Reform or be reformed!

In the past couple of years, CAS has come under enormous pressure from the political leadership to produce visible achievements. The loss of independence of the Russian Academy of Sciences, the successor to the Soviet Academy of Sciences on which CAS was modelled, in a top-down reform in 2013 (see Box 13.2), has sent a chilling signal: if CAS does not reform itself, others will. This realization prompted current CAS President Bai Chunli to take advantage of Xi's call for CAS to become 'a pioneer in four areas' (see p. 628) to propose a sweeping reform of the academy through a new Pioneering Action Initiative (*shuaixian xingdong jihua*). The aim of this initiative is to orient the academy towards the international frontier of science, major national demands and the battleground for the national economy by re-organizing existing institutes into four categories:

- centres of excellence (*zhuoyue chuangxin zhongxin*) focused on basic science, especially in those areas where China has a strong advantage;
- innovation academies (*chuangxin yanjiuyuan*) targeting areas with underdeveloped commercial potential;
- centres of big science (*dakexue yanjiu zhongxin*) built around large-scale facilities to promote domestic and international collaboration; and
- institutes with special characteristics (*tese yanjiusuo*) devoted to initiatives that foster local development and sustainability (Cyranoski, 2014a).

Box 23.4: Water body pollution control and treatment: a mega-engineering programme

The mega-engineering programme of water body pollution control and treatment has been designed to address the technology bottleneck in China's efforts to control and treat pollution of water bodies. In particular, the programme aims to achieve a breakthrough in key and generic technologies related to water pollution control and treatment, such as industrial pollution source control and treatment, agricultural non-point source pollution control and treatment, urban sewage treatment and recycling, purification and the ecological restoration of water bodies, drinking water safety and water pollution monitoring and early warning.

The programme focuses on four rivers (Huai, Hai, Liao and Songhua), three lakes (Tai, Chao and Dianchi) and the Three Gorges Reservoir, the largest dam in the world. Projects have been carried out within the six major themes of monitoring and early warning, city water environment, lakes, rivers, drinking water and policies.

The Ministry of Environmental Protection and the Ministry of Housing and Urban and Rural Construction are in charge of the programme, which got under way on 9 February 2009 with a budget of more than RMB 30 billion. The first stage of the programme to early 2014 targeted breakthroughs in key technologies to control source pollution and reduce wastewater discharge. The second stage is currently targeting breakthroughs in key technologies to fix the water bodies. The main goal of the third stage will be to make technological breakthroughs in comprehensive control of the water environment.

The first stage focused on the entire process wastewater treatment technology for heavily polluting industries, comprehensive treatments for heavily polluted rivers and lakes suffering from eutrophication, non-point source pollution control technology, water quality purification technologies, water-related environmental risk assessment and early warning, as well as key remote monitoring technology. Comprehensive demonstration projects were carried out in the Tai Lake basin to improve water quality and eliminate water from rivers running through cities that is of Class-V quality, which means it is only suitable for irrigation and landscaping. The first-stage projects also targeted problems related to drinking water. There have also been some achievements in water resources protection, water purification, safe distribution, monitoring, early warning, emergency treatment and safety management.

Source: http://nwpcp.mep.gov.cn

The reclassification of the CAS institutes and their scientists was still under way in 2015. It must be said that the initiative itself is self-congratulatory, as the academy is still resting on its past achievements, with little consideration for whether this new initiative may be good for the nation as well as for the academy. This explains why some are sceptical about the necessity of maintaining such a gigantic organization, a model not found anywhere else in the world.

The initiative offers the academy a bright future, as long as it can count on sizable government funding – but that is nothing new. Many of the goals that President Bai Chunli proposed for the Pioneering Action Initiative are identical to those of his predecessor, Lu Yongxiang, through his own Knowledge Innovation Programme. Nor is there any guarantee that these goals will be fulfilled through the reform.

The Pioneering Action Initiative is pivoting institutions into a new matrix so as to boost collaboration within the academy and concentrate on tackling key research questions, which has a certain logic. Implementation will be tough, though, since many institutes do not fit easily into any of the four defined categories. Another worry is that the initiative may not necessarily encourage collaboration with scientists external to CAS. The danger is that CAS may actually become even more hermetic and isolated than before.

The timing of the reform may also complicate matters. The reform at CAS coincides with the nationwide reform of public institutions (*shiye danwei*) launched in 2011. In general, the country's 1.26 million public institutions of education, research, culture and health care, which have more than 40 million employees, fall into two types. CAS institutes that fall into Type 1 are to be fully financed from the public purse and will be expected to fulfil only the tasks set by the state. Type II CAS institutes, on the other hand, will be allowed to supplement partial public funding with income earned through other activities, including through government procurement of their research projects, technology transfer and entrepreneurship. The reform will thus have implications both for the institutes and for individual scientists, in terms of the amount of stable funding they receive and the level of salaries, as well as the scope and importance of the executed projects. It is also likely that some CAS institutes will be corporatized, as this is what has happened to China's application-oriented R&D institutes since 1999. Consequently, CAS will need to become a leaner institution, as the state may not always be willing or able to finance such a costly academy.

Box 23.5: **Large-scale advanced nuclear power stations: a mega-engineering programme**

In 2015, China had 23 operable nuclear reactors and a further 26 were under construction. The country's large-scale nuclear power station programme has three components: advanced pressurized water reactors (PWR), special high-temperature reactors (HTR) and used fuel reprocessing. The central government is expected to invest RMB 11.9 billion and RMB 3 billion respectively in the two nuclear reactor sub-programmes.

The PWR sub-programme is being implemented by the State Nuclear Power Technology Corporation (SNPTC). It aims to digest and absorb imported third-generation nuclear power technology, which will then serve as the basis for developing more powerful large-scale advanced PWR technology, and to generate indigenous intellectual property rights.

The programme has three stages. Initially, the Westinghouse Electric Company, now a unit of Japanese engineering and electronics giant Toshiba, is helping SNPTC to build four advanced, passive units with an installed capacity of about 1 000 MW each (AP 1 000 units), through which SNPTC masters the basic design capability for third-generation nuclear power technology. At the second stage, SNPTC will develop a standardized design capability of AP 1 000 units, as well as the ability to build AP 1 000 units in both coastal and inland areas, with support from Westinghouse. By the third stage, SNPTC should be capable of designing advanced, passive third-generation nuclear reactors units of 1400 MW (Chinese AP 1 400); it should also be ready to build a CAP 1 400 demonstration unit and undertake a pre-research programme for the larger CAP 1 700 units.

The programme was launched on 15 February 2008. The construction of the AP 1 000 units in Sanmen in Zhejiang province and Haiyang in Shandong province got under way in 2009. Construction was put on hold, however, after the earthquake-induced nuclear disaster in Japan in March 2011 (see Chapter 24). Construction resumed in October 2012 and four AP 1 000 units are now expected to be online by late 2016.

SNPTC has been co-ordinating domestic nuclear power equipment manufacturers, research institutes and universities, which are in the process of assimilating imported equipment design and manufacturing technology and localizing key equipment used in the AP 1 000. Some key equipment has already been shipped to the Sanmen and Haiyang sites. In 2014, the first reactor pressure vessel for the second AP 1 000 unit in Sanmen was manufactured domestically.

In December 2009, SNPTC and the China Huaneng Group formed a joint venture to start a CAP 1 400 demonstration project in Shidaowan in Shandong province. The conceptual design passed the state's evaluation test at the end of 2010 and a preliminary design was completed in 2011. In January 2014, the National Energy Administration organized the expert review of the project and, in September, the National Nuclear Safety Administration approved the design safety analysis following a 17-month review. Key equipment for CAP 1 400 is currently being manufactured and the related demonstration project, which is due to start soon, is expected to localize 80% of the nuclear island equipment. Safety tests for key components used in CAP 1 400 unit have also gone ahead. The demonstration and standardized units of the CAP 1 400 demonstration project should be operational by 2018 and 2019 respectively.

Meanwhile, also in Shidaowan, a HTR-20 demonstration project is already up and running. The project will develop the world's first fourth-generation demonstration reactor, on the basis of the 100 MW HTR-10 prototype pebble-bed reactor developed by Tsinghua University.

Tsinghua University began building the HTR-10 reactor back in 1995. This fourth-generation nuclear energy technology is modelled on the German HTR-MODUL. The reactor was fully operational by January 2003. HTR-10 is claimed to be fundamentally safer, potentially cheaper and more efficient than other nuclear reactor designs. Operated at high temperatures, it generates hydrogen as a by-product, thus supplying an inexpensive and non-polluting fuel for fuel cell-powered vehicles.

Huaneng, the China Nuclear Energy Construction Company and Tsinghua University have established a joint venture to scale up the HTR experimental design and engineering technology, as well as high-performance fuel cell batch preparation techniques. Postponed after the Fukushima nuclear disaster in March 2011, the project finally got under way in late 2012. When it comes online in 2017, the Shidaowan project will have its first two 250 MW units, which together will drive a steam turbine generating 200 MW.

The third component of this mega-engineering programme concerns the construction of a large commercial spent fuel reprocessing demonstration project to achieve a closed fuel cycle.

Source: www.nmp.gov.cn

Rethinking government funding of research

Another major reform is this time shaking up the way in which the Chinese government funds research. China has seen rising central government expenditure on science and technology over the past decade. With RMB 236 billion (US$ 38.3 billion) in 2013, spending on science and technology accounted for 11.6% of the central government's direct public expenditure. Of this, R&D expenditure has been estimated at about RMB 167 billion (US$ 27 billion) by the National Bureau of Statistics (2014). As new national science and technology programmes had been added over the years, especially the mega-engineering programmes introduced under the *Medium- and Long-Term Plan* after 2006, funding had become decentralized and fragmented, resulting in widespread overlap and an inefficient use of funds. For example, about 30 different agencies administered the central government R&D funding through some 100 competitive programmes up until the launch of the new reform. To compound matters, pervasive corruption and misaligned incentives were seen as weakening the vitality of China's research enterprise (Cyranoski, 2014b). Change seemed inevitable.

Once again, the reform was instigated under the pressure of the political leadership. Initially, the measures proposed by the Ministry of Science and Technology (MoST) and the Ministry of Finance only made small adjustments to the existing system. All the major programmes were to be maintained and linked to one another, with the integration of small programmes, and new procedures for supporting research were to be introduced, along with other measures to avoid repetition and strengthen co-ordination between ministries. The Central Leading Group for Financial and Economic Affairs turned down several drafts of the reform proposal. It was only after the Central Leading Group for Financial and Economic Affairs contributed substantial input of its own that the measure was finally approved by the Central Leading Group for the Deepening of Comprehensive Reform, the Politburo of the CCP's Central Committee and the State Council. The reform re-organizes the nation's R&D programmes into five categories:

- Basic research through the National Natural Science Foundation of China, which currently distributes many of the small-scale competitive grants;
- Major national science and technology programmes, which are presumably the mega-science and mega-engineering programmes under the *Medium- and Long-Term Plan* to 2020;
- Key national research and development programmes, which presumably succeed the State High-Technology R&D Programme, also known as the 863 Programme, and the State Basic Research and Development Programme, also known as the 973 Programme;[5]
- A special fund to guide technological innovation; and
- Special programmes to develop human resources and infrastructure (Cyranoski, 2014b).

These five categories translate into some RMB 100 billion (US$ 16.36 billion), or 60% of the central government's funding for research in 2013, which will be handled by professional organizations specializing in research management by 2017. MoST, which distributed RMB 22 billion (US$ 3.6 billion) in public R&D funding in 2013, will gradually concede its role of administering the funding for programmes under its jurisdiction, most noticeably the 863 and 973 Programmes (Figure 23.8). Some other ministries with a portfolio for science and technology will likewise relinquish their power to distribute public research funds. In return, MoST will survive the reform intact, rather than being dissolved as had been debated for quite some time. The ministry will henceforth be in charge of formulating policy and monitoring the use of funding. In line with the reform, the ministry is restructuring to reorganize relevant departments. For example, its Planning and Development Bureau and Scientific Research Conditions and Finance Bureau have been merged to form the new Resource Allocation and Management Bureau to strengthen operational oversight of the future interministerial conference mechanism. Officials at bureau chief level have also been reshuffled within the ministry.

The interministerial conference mechanism is led by MoST with the participation of the Ministry of Finance, National Development and Reform Commission (NDRC) and others. The interministerial conference is responsible for planning and reviewing strategies for S&T development, determining national S&T programmes and their key tasks and guidelines and overseeing the professional research management organizations that will be formed to review and approve funding for national science and technology programmes. The interministerial conference will be supported by a committee responsible for strategic consulting and comprehensive review, which will be convened by MoST and composed of leading experts from the scientific community, industry and various economic sectors.

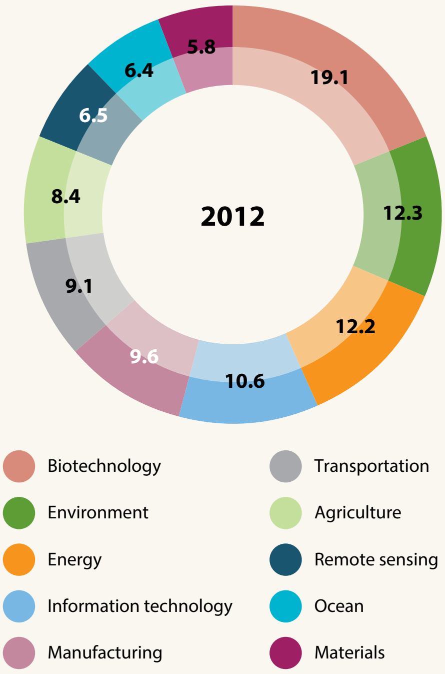
At the operational level, professional research management organizations will be established. Through a 'unified platform' or a national S&T information management system, they will organize project submission, evaluation, management and assessment. MoST and the Ministry of Finance will be responsible for reviewing and supervising the performance evaluation of the funding for national science and technology programmes, evaluating the performance of members of the strategic consulting and comprehensive review committee and the performance of the professional research management organizations. The procedures of programmes and projects will be adjusted as part of the dynamic evaluation and

5. For details of these programmes, see the *UNESCO Science Report 2010.*

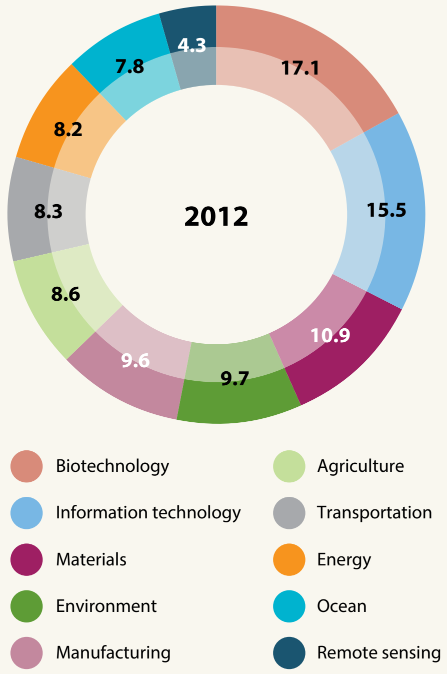
Figure 23.8: **Priorities of China's national research programmes, 2012**

PRIORITIES OF CHINA'S NATIONAL PROGRAMME FOR HIGH-TECH R&D (863 PROGRAMME)

Distribution of new projects by field (%)

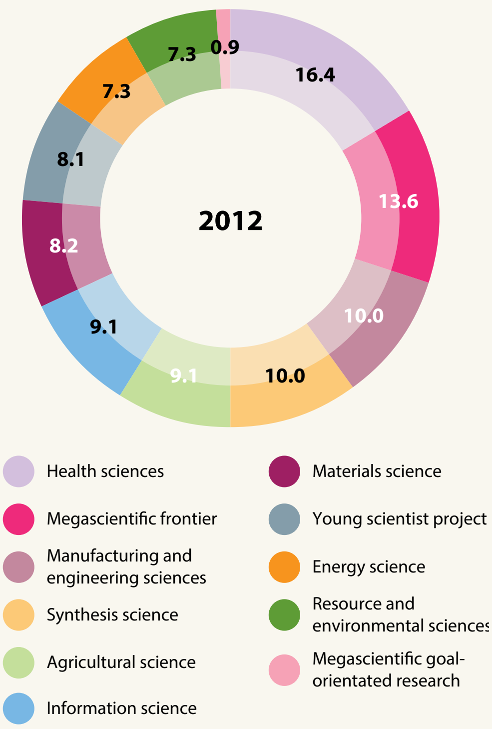


Distribution of budget for new projects by field (%)

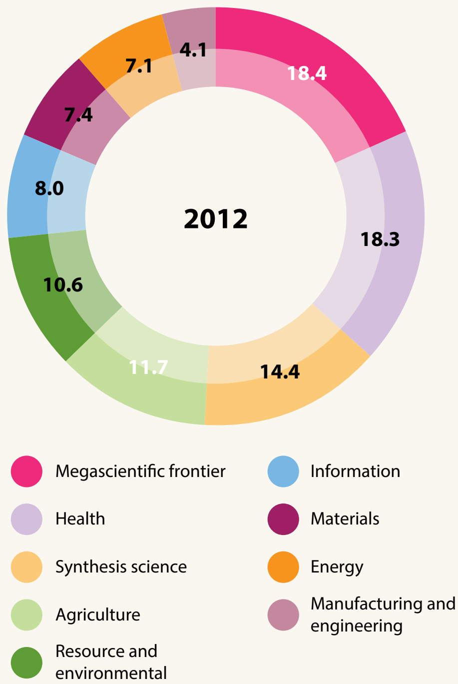


PRIORITIES OF CHINA'S NATIONAL PROGRAMME FOR KEY BASIC R&D (973 PROGRAMME)

Distribution of new projects by field (%)



Distribution of budget by field (%)



Source: Planning Bureau of Ministry of Science and Technology (2013) *Annual Report of the National Programmes of Science and Technology Development.*

monitoring process. The 'unified platform' will also collect and report information on national S&T programmes, including budget, personnel, progress, outcomes and evaluation and assessment, thus subjecting the entire process of research management to public scrutiny.

As yet, it is unclear how the professional research management organizations will be established and, above all, how they will operate. One possibility would be to transform the existing research management organizations, including those under MoST and other government ministries handling similar tasks. The question then becomes how to avoid 'putting new wine into an old bottle,' as opposed to changing fundamentally the way in which the government funds national science and technology programmes. The idea of professional research management organizations has been inspired by the UK model; in the UK, public funds destined for research are distributed through seven research councils for the arts and humanities, biotechnology and biological sciences, engineering and physical sciences, economic and social sciences, medical sciences, the natural environment and science and technology. This begs the question of how to integrate the existing programmes under different ministries according to the logic of scientific research rather than arbitrarily assigning them to the various professional research management organizations. Meanwhile, some government ministries may be reluctant to relinquish their control over funding.

An environmental action plan

China, along with India and other emerging economies, has long insisted on the principle of 'common but differentiated responsibilities' in dealing with global climate change. However, as the world's largest greenhouse gas (GHG) emitter, China is most susceptible to the adverse effects of climate change, mainly in agriculture, forestry, natural ecosystems, water resources (Box 23.4) and coastal areas. Irreversible climate change could throttle China's rise as a great power and environmental damage, GHG emissions and rising temperatures could derail China's path to modernity. Indeed, China has been facing the challenge of balancing its multiple development goals, which range from industrialization, urbanization, employment and exports to sustainability and include the target of doubling GDP by 2020. By reducing its GHG emissions and cleaning up the environment, the political leadership is also likely to gain further support from the emerging middle class; this support will be necessary to maintain the legitimacy of the Chinese Communist Party and help overcome other domestic challenges.

These concerns have prompted the Chinese government to come up with policies for energy conservation and GHG emissions reduction. In 2007, NDRC released the National Climate Change Programme, which proposed reducing unit GDP energy consumption by 20% by 2010 from 2005 levels, in order to reduce China's carbon dioxide (CO_2) emissions. Two years later, the government went a step further, establishing a target of reducing unit GDP CO_2 emissions by 40–45% by 2020 from 2005 levels. The reduction in energy consumption became a binding target in the *Eleventh Five-Year Plan* (2006–2010). The *Twelfth Five-Year Plan* (2011–2015) set the targets of reducing unit GDP energy consumption by 16% and CO_2 emissions by 17% by 2015. However, China did not meet the energy target in the *Eleventh Five-Year Plan* (2005–2010) and the *Twelfth Five-Year Plan* was also behind schedule in the first three years for reaching its targets, despite the enormous pressure brought to bear on local officials by the central leadership.

On 19 September 2014, China's State Council unveiled an *Energy Development Strategy Action Plan (2014–2020)* which promised more efficient, self-sufficient, green and innovative energy production and consumption. With the cap of annual primary energy consumption set at 4.8 billion tons of standard coal equivalent until 2020, the plan's long list of targets for building a modern energy structure includes:

- reducing unit GDP CO_2 emissions by 40–50% over 2005 levels;
- increasing the share of non-fossil fuels in the primary energy mix from 9.8% (2013) to 15%;
- capping total annual coal consumption at roughly 4.2 billion tons;
- lowering the share of coal in the national energy mix from the current 66% to less than 62%;
- raising the share of natural gas to above 10%;
- producing 30 billion m^3 of both shale gas and coalbed methane;
- having an installed nuclear power capacity of 58 Gigawatts (GW) and installations with a capacity of more than 30 GW under construction;
- increasing the capacity of hydropower, wind and solar power to 350 GW, 200 GW and 100 GW respectively; and
- boosting energy self-sufficiency to around 85%.

As China burned 3.6 billion tons of coal in 2013, capping total coal consumption at roughly 4.2 billion tons means that China can only increase its coal usage by roughly 17% by 2020 from 2013 levels. The cap also means that annual coal consumption may only grow by 3.5% or less between 2013 and 2020. To compensate for the drop in coal consumption, China plans to expand its nuclear energy production with the construction of new nuclear power stations (Box 23.5) and the development of hydropower, wind and solar energy (Tiezzi, 2014).

There are several reasons for China's emphasis on diversifying its energy mix. In addition to environmental considerations, China is eager to reduce its reliance on foreign energy suppliers. Currently, China receives nearly 60% of its oil and over 30% of its natural gas from foreign sources. For domestic production to make up 85% of total energy consumption by 2020, China will need to increase its production of natural gas, shale gas and coalbed methane. The new energy action plan also calls for deepwater drilling, as well as for the development of oil and gas extraction in its neighbouring seas by undertaking both independent extraction projects and co-operative projects with foreign countries (Tiezzi, 2014).

A week before the announcement of the new energy action plan, President Xi Jinping signed a joint climate change agreement with US President Barack Obama, in which China undertook to raise the share of non-fossil fuel sources to 20% of its energy mix by 2030. China also agreed to slow down then stop the increase in its GHG emissions by 2030; in turn, the USA pledged to reduce its own GHG emissions by up to 28% by 2025 relative to 2005 levels. Both presidents also agreed to co-operate in the fields of clean energy and environmental protection. Whereas China and the USA had blamed one another for the failure of the 2009 summit on climate change in Copenhagen to reach an agreement on setting emissions reduction targets, now there is strong hope that the negotiations might culminate in an agreement at the climate change conference in Paris in late 2015.

Amid all these positive developments, the Standing Committee of the National People's Congress – China's legislature – passed the *Amendment to Environmental Protection Law* on 24 April 2014, marking the end of a three-year revision of China's environmental protection law. The new law, which took effect on 1 January 2015, stipulates harmonizing socio-economic development with environmental protection and, for the first time, establishes clear requirements for building an ecological civilization. Perceived to be the most stringent in China's environmental protection history, the law toughens the penalties for environmental offences with specific articles and provisions for tackling pollution, raising public awareness and protecting whistle-blowers. It also places greater responsibility and accountability on local governments and law enforcement bodies for environmental protection, sets higher environmental protection standards for enterprises and imposes harsher penalties for such acts as tampering with and falsifying data, discharging pollutants deceptively, not operating pollution prevention and control facilities normally and evading supervision, among others (Zhang and Cao, 2015).

CONCLUSION

Realizing the 'China Dream' will not be unconditional

China's new political leadership has placed STI at the core of the reform of its economic system, as innovation can help not only with restructuring and transforming the economy but also with solving other challenges that China faces – from inclusive, harmonious and green development to an ageing society and the 'middle income trap.' The period from now to 2020 seems to be critical for the comprehensive deepening of reform, including the reform of the S&T system. As we have seen, new initiatives have been launched to reform the Chinese Academy of Sciences and the centrally financed national S&T programmes, in order to increase China's chances of becoming an innovation-oriented, modern nation by 2020.

The reform is necessary but it is still too early to predict whether it will lead China in the right direction and, if so, how quickly it will contribute to China's ambition of becoming an innovation-oriented nation. Particular concerns are the extent to which the reform reflects a 'top-level design', at the expense of the consultations with stakeholders and the public, coupled with the integration of bottom-up initiatives that proved crucial for the formulation and implementation of S&T policy in the earlier reform and open-door era. The merit of the 'whole nation system' also needs to be carefully assessed against the trend of globalization, which not only served as the backdrop to China's rise in economic and technological terms during the reform and open-door era but also brought China enormous benefits.

As we have seen, the level of dependence of Chinese enterprises on foreign core technologies is of some concern. The current political leadership has reacted by setting up an expert group under Vice-Premier Ma Kai to identify industrial 'champions' capable of concluding strategic partnerships with foreign multinationals. This resulted in Intel acquiring 20% of the shares in Tsinghua Unigroup, a state company emanating from one of the country's most prestigious universities, in September 2014. At the time of writing in July 2015, the *Wall Street Journal* had just revealed an offer by Tsinghua Unigroup to purchase Micron, a US manufacturer of semiconductors, for € 20.8 billion. Should the deal go ahead, it will be the biggest foreign takeover concluded by a Chinese firm since the China National Offshore Oil Corporation purchased the Canadian oil and gas company Nexen Inc. in 2012 for US$ 15 billion.

Knowledge transfer is evidently embedded in China's foreign direct investment and the efforts of the returnees, who are now active at the forefront of technology and innovation in China. Although the political leadership still calls for globalization to be embraced, recent cases of bribery and anti-monopoly moves targeting multinational companies operating in China, coupled with the restrictions on access to information and the current anti-Western values rhetoric, may lead to an exodus of capital and talent.

The smooth running of China's S&T system and, indeed, the economy as a whole, can be impacted by unstable domestic developments and unexpected external shocks. During the 30-plus-year reform and open-door era from 1978 onwards, scientists and engineers enjoyed a largely stable and favourable working environment which fostered professional satisfaction and career advancement. Chinese science and technology progressed at an impressive pace in an environment that was less politicized, interventionist and disruptive than today. China's scientific community is conscious that its work environment will need to be conducive to creativity and the cross-pollenization of ideas, if it is to contribute effectively to achieving the 'China Dream' envisaged by the country's political leadership.

KEY TARGETS FOR CHINA

- Raise GERD to 2.50% of GDP by 2020;
- Raise the contribution of technological advances to economic growth to more than 60% by 2020;
- Limit China's dependence on imported technology to no more than 30% by 2020;
- Become, by 2020, one of the top five countries in the world for the number of invention patents granted to its own citizens and ensure that Chinese-authored scientific papers figure among the world's most cited;
- Reduce (unit GDP) CO_2 emissions by 40–50% by 2020 from 2005 levels;
- Increase the share of non-fossil fuels in the primary energy mix from 9.8% (2013) to 15% by 2020;
- Cap annual coal consumption at roughly 4.2 billion tons by 2020, compared to 3.6 billion tons in 2013, and lower the share of coal in the national energy mix from 66% at present to less than 62% by 2020;
- Raise the share of natural gas to above 10% by 2020;
- Produce 30 billion m^3 of both shale gas and coalbed methane by 2020;
- Achieve an installed nuclear power capacity of 58 Gigawatts (GW) and installations with a capacity of more than 30 GW under construction by 2020;
- Increase the capacity of hydropower, wind and solar power to 350 GW, 200 GW and 100 GW respectively by 2020;
- Boost energy self-sufficiency to around 85%.

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