PLANNING FOR INNOVATION
Understanding China's Plans for Technological, Energy, Industrial, and Defense Development

A report prepared for the
U.S.-China Economic and Security Review Commission

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ACRONYMS AND ABBREVIATIONS

3D	Three-dimensional, refers to printing technology
3G	Third-generation, refers to mobile telecommunications technology
4G	Fourth-generation, refers to mobile telecommunications technology
5G	Fifth-generation, refers to mobile telecommunications technology
863 Plan	National High-Technology Research and Development Plan, 高技术研究发展计划
973 Plan	National Basic Research Plan, 国家重点基础研究发展计划
995 Plan	New High-Technology Weapons Plan, 高新工程
995 LSG	New High-Technology and Engineering Leadership Small Group, 中央军委新高科技工程领导小组–995 LSG
AM	Additive manufacturing
Beidou	Beidou navigation satellite system, 北斗卫星导航系统
BEV	Battery electric vehicle
BUAA	Beijing University of Aeronautics and Astronautics, 北京航空航天大学
CAE	Chinese Academy of Engineering, 中国工程院
CAGR	Compound annual growth rate
CAS	Chinese Academy of Sciences, 中国科学院
CCP	Chinese Communist Party, 中国共产党
CDMA	Code division multiple access
CEO	Chief executive officer
CMC	Central Military Commission, 中央军事委员会
CNC	Computerized numerical control
COD	Chemical oxygen demand
COSTIND	Commission for Science, Technology, and Industry for National Defense, 国防科学技术工业委员会
EU	European Union
EV	Electric vehicle
FCC	US Federal Communications Commission
FCEV	Fuel cell electric vehicle
FDI	Foreign direct investment
FPD	Flat-panel display
FYP	Five-Year Plan, 五年规划
GAD	PLA General Armament Department, 中国人民解放军总装备部
GDP	Gross domestic product
GLD	PLA General Logistics Department, 中国人民解放军总后勤部

GLONASS	Global Navigation Satellite System (operated by Russian Aerospace Defense Forces)
GNSS	Global navigation satellite system
GPS	Global Positioning System (operated by the United States)
GW	Gigawatts
HSR	High speed rail
IaaS	Infrastructure as a service
ICT	Information and communications technology
IDC	Internet Data Corporation
IDDS	Innovation-driven development strategy
IP	Intellectual property
IPR	Intellectual property rights
ITU	International Telecommunications Union
IMT	International Mobile Telecommunication
LBS	Location-based services
LMD	Laser metal deposition
LSG	Leadership Small Group, 领导小组
LWECP	Long-Term Weapons and Equipment Construction Plan, 长期武器装备建设规划
MEP	Ministry of Environmental Protection, 中华人民共和国环境保护部
MIIT	Ministry of Industry and Information Technology, 中华人民共和国工业和信息化部
MLDP	Medium- and Long-Term Defense Science and Technology Development Plan, 国防科技工业中长期科学和技术发展规划
MLP	Medium- and Long-Term Plan for Science and Technology Development, 国家中长期科学和技术发展规划纲要
MLR	Ministry of Land and Resources, 中华人民共和国国土资源部
MOFCOM	Ministry of Commerce, 中华人民共和国商务部
MOF	Ministry of Finance, 中华人民共和国财政部
MOHURD	Ministry of Housing and Urban-Rural Development, 中华人民共和国住房和城乡建设部
MOST	Ministry of Science and Technology, 中华人民共和国科技部
MSG	Military Strategic Guidelines, 军事战略方针
MW	Megawatts
MWECP	Medium-Term Weapons and Equipment Construction Plan, 中期武器装备建设规划
NEA	National Energy Administration, 国家能源局
NDRC	National Development and Reform Commission, 中华人民共和国国家发展与改革委员会
NIST	US National Institute of Standards and Technology

OECD	Organization for Economic Co-operation and Development
OEM	Original equipment manufacturer
PaaS	Platform as a service
PHEV	Plug-in hybrid electric vehicle
PLA	People's Liberation Army, 中国人民解放军
PMO	Plan management organization
PRC	People's Republic of China, 中华人民共和国
R&D	Research and development
RMB	Renminbi, 人民币
S&T	Science and technology
SaaS	Software as a service
SASTIND	State Administration for Science, Technology, and Industry for National Defense, 国家国防科技工业局
SEI	Strategic Emerging Industries, 战略性新兴产业
SLOC	Sea lanes of communication
SME	Small and medium enterprises
STI	Science, technology, and innovation
SWECP	Short-Term Weapons and Equipment Construction Plan, 短期武器装备建设规划
TPP	Trans-Pacific Partnership
WEDS	Weapons and Equipment Development Strategy, 武器装备发展战略
WECP	Weapons and Equipment Construction Plan, 武器装备建设规划/计划
WTO	World Trade Organization
UAV	Unmanned aerial vehicle
US	United States

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EXECUTIVE SUMMARY

In the global race for economic, technological, and innovation leadership, China is a late entrant but has made impressive progress in closing the gap at the top by harnessing abundant resources accumulated through nearly four decades of high-octane growth and a voracious appetite for foreign technology and know-how. One of the principal ways this is being conducted is through top-down, state-directed plans. These planning instruments have proliferated in number, scale, and influence in the past few decades. In the science and technology (S&T) sector alone, there are as many as 100 plans. Some of the most prominent include the Five-Year Plans (FYP) for S&T Development, the 2006–2020 Medium and Long-Term S&T Development Plan (MLP), the Strategic Emerging Industries initiative, and the newly introduced Made in China 2025 plan.

Key Findings

This report offers a critical assessment of the state plans responsible for China's civilian and defense-related S&T, industrial, and energy development and their economic and security implications for the United States. A number of key findings emerge from this study:

- **Much promise, mixed results:** Plans and projects individually and in aggregate have put forward lofty aspirations and goals in advancing China's development, but actual overall performance has been decidedly mixed. While there have been some noteworthy achievements, the vast majority of plans have delivered far short of what they have promised. Many factors contribute to these shortcomings, from weak R&D capabilities to inadequate funding to structural flaws in the S&T management system.
- **Predominantly lower-end innovation with "Chinese characteristics":** China's S&T development has been overwhelmingly at the lower end of the imitation-innovation spectrum, especially in:
    - **Advanced imitation**, or what the Chinese call 're-innovation,' which are technologies based upon foreign-derived technology and knowledge but reverse engineered and adapted to Chinese requirements. Key examples are high speed rail and the latest generation of Western-designed nuclear reactors.
    - **Crossover innovation**, which refers to products jointly developed by Chinese and foreign partners with significant technology and knowledge transfers to the Chinese side that result in the creation of an advanced R&D base. There is still considerable reliance on foreign countries for technological and managerial input to ensure that projects come to fruition. The newly rolled-out C919 airliner is a prime example of crossover innovation.
    - **Incremental innovation,** which is the limited updating and improvement of existing indigenously developed systems and processes.
- **Pivoting to higher-end innovation:** The Chinese authorities have made the advancement to higher-end innovation a top priority in their latest development plans. At the 5th Plenum of the 18th Communist Party Congress in November 2015, Xi Jinping pointed out that a number of strategic technologies and research domains have been selected with the intention of pursuing major breakthroughs by 2030. They include aero-engines, quantum communications, intelligent manufacturing and robotics, deep space and deep sea probes, major new materials, and neurosciences.

- **Fostering more market-driven development:** The Xi Jinping administration is seeking to broaden China's long-standing model of top-down, state-led science, technology, and innovation development to embrace market-driven and bottom-up drivers under a newly passed innovation-driven development strategy. New policies and reforms are being drawn up, especially tied to the 13th FYP, incentivizing researchers, entrepreneurs, universities, and private companies to engage more intensively in research and development and higher-end innovation. Measures put forward include improving intellectual property protection, tackling industrial monopolies, supporting the development of the venture capital market, and implementing more supportive fiscal and taxation policies. If these initiatives are effectively implemented, this would allow innovation in China to become more balanced between state and market, sustainable, and internationally competitive.
- **The emergence of direct Sino-US defense technological competition:** The United States has long enjoyed a huge defense technological pre-eminence over China, but this gap has narrowed over the past one to two decades to the extent that the United States is now having to embark on a major new defense S&T offensive to preserve its dwindling superiority. The Third Offset Strategy and the Defense Innovation Initiative are the primary vehicles in the Pentagon's efforts at responding to the advances being made by China and other potential adversaries. Although these plans are modest when compared to the enormous and costly scale of the Cold War arms race between the United States and the Soviet Union, they nonetheless signal the first steps of direct Sino-US defense technological competition.
- **Innovation in China's defense S&T sector is more successful than in the civilian arena:** China has invested heavily in its defense-related S&T plans and has enjoyed far more success than in the civilian sectors, as demonstrated in both the quality and quantity of output emerging from the research, development, and production pipeline over the past decade or more. This impressive progress is likely to continue and even accelerate in response to calls from top leaders, abundant funding, and assessments of an intensifying global revolution in military affairs.
- **The Chinese defense S&T apparatus is moving to higher-end innovation:** The Chinese defense S&T system appears to be making an important shift from focusing on absorption to the development of more innovative capabilities, especially in meeting the PLA's more demanding requirements. With considerable attention paid to the United States as China's primary military technological competitor, much of the R&D is directed to asymmetric and deterrence capabilities. Despite the progress being made, deep-seated structural problems in the defense S&T and armaments system represent serious barriers to continuing improvement. These obstacles include compartmentalization, weak institutionalization, and an underdeveloped governance regime.
- **China's technological development has so far been of overall positive benefit for companies and consumers, but the longer-term horizon is more uncertain:** A detailed review of eleven industries indicates that at present, most of these industries have a positive impact for the United States (see table). This is because of China's large market demand for the technologies and the lack of current Chinese indigenous expertise or technology know-how. Over the next several years, US firms will face intensifying competition as China's domestic industries make technological advances with support from state plans. This is likely to be the case for the 5G technology, cloud computing, global navigation satellite systems, and integrated circuits

sectors. Over the longer-term, ten-year horizon, the Chinese industries that will provide the toughest competition for the United States will be information and communications technology, 5G, cloud computing, global navigation satellite systems, and integrated circuits. In other sectors, including additive manufacturing, advanced robotics, biopharmaceuticals, medical devices, electric vehicles, and nanomaterials, the impact on US firms from China's technology advances will be more mixed.

- **Domestic demand drives innovation in the energy sector:** S&T efforts in the Chinese energy sector are framed in the context of the pursuit of indigenous innovation, which is the desire to localize production and intellectual property. The Chinese energy industry has been successful in areas such as coal-fired power plants where domestic demand is high. They have been less successful and have devoted fewer resources in areas where they have traditionally been relatively modest consumers, such as gas turbines. As energy demands shift, the Chinese energy sector is likely to seek greater intellectual property in the areas where they lag.

The effect of Chinese S&T policies on US economic competitiveness in eleven sectors

Industry	**Current**	**Short term (1–3 years)**	**Long term (10+ years)**
Information and communications technology			
5G technology	positive	mixed—too early to tell	negative
Cloud computing	positive	mixed—with negative implications	negative
Global navigation satellite systems	positive	mixed—with negative implications	negative
Integrated circuits	mixed—with negative implications	mixed—with negative implications	negative
Manufacturing			
Additive manufacturing	positive	mixed—with positive implications	negative
Advanced robotics	limited positive	positive	mixed—with positive implications
Nanomaterials	limited negative	positive	mixed—too early to tell
Transportation			
Electric vehicles	negative	negative	mixed—with positive implications
High speed rail	limited positive	limited positive	limited positive
Medical and healthcare			
Biopharmaceuticals	positive	positive	mixed—with positive implications
Medical Devices	positive	positive	mixed—with positive implications

- **Techno-national opportunism and indigenous innovation are powerful strategic principles in the nature and approach of Chinese state plans:** Techno-nationalism advocates that a state-controlled and closed-door approach to technological and industrial development is the best way to safeguard national security, economic competiveness, and international status. Emphasis is placed on nurturing indigenous capabilities through the adoption of highly regulated protectionist regimes that sharply restrict foreign direct investment but encourage the one-way importation of advanced technology and knowledge. The MLP is a leading example of a plan that is avowedly techno-nationalistic in nature.

  Hand in glove with techno-nationalism is indigenous innovation, which is widely referred to in Chinese state plans. What indigenous innovation actually means, however, is far from clear. When the term first appeared in the MLP, it was defined as a way to promote original innovation, re-assembling existing technologies in different ways to produce new breakthroughs, and the absorption and upgrading of imported technologies, of which the latter is the most important way to advance innovation. This continues to be the standard definition of indigenous innovation to the present day.

  The Chinese authorities have devised at least half-a-dozen policy instruments to advance their science, technology, energy, and industrial development guided by the techno-nationalist and indigenous innovation principles:

  1. sectoral protectionism
  2. the cultivation of local and national champions
  3. pushing hard for technology transfers
  4. the use of state catalogues to regulate investment and technology imports
  5. the promotion of Chinese technology standards domestically and internationally
  6. an increasingly vigorous "going out" strategy to open up foreign markets for Chinese products as well as to secure energy and other critical supplies for the country

- **Estimating the impact of Chinese high-tech imports on US jobs:** A sensitivity analysis was conducted to calculate the range of outcomes that can be reasonably anticipated regarding the magnitude of impacts to the US labor market from Chinese manufactured imports out to 2020. To begin with, a range of estimates was developed based on trading scenarios associated with eight high-tech sectors: telecommunications equipment, electric vehicles, medical devices, additive manufacturing, advanced robotics, high speed rail, biopharmaceuticals, and integrated circuits. The worst-case outcome is that the United States would face a $55 billion increase in net imports from China by 2020. The best-case scenario is that US net imports from China would decline by almost $35 billion by 2020. Using the worst-case $55 billion figure, our estimate is that the United States would lose 431,600 manufacturing jobs by 2020. For the best-case scenario of a net $35 billion gain in US exports, US manufacturing employment would increase by 273,100 jobs. It is highly unlikely that either of these extreme values will be realized. A mixed outcome, in which the overall impact on US net imports from China close to zero, is most likely.

In conclusion, state plans have become a convenient, almost indispensable, policy tool for the Chinese authorities, even if their overall effectiveness is questionable. While there have been some noteworthy achievements, the large majority of plans have delivered far short of what they have promised. Many factors contribute to these shortcomings, from weak R&D capabilities to inadequate funding to structural flaws in the S&T management system. All the indicators suggest, however, that the Chinese authorities will most likely channel even more resources to these plans, while at the same time carrying out reforms to address these weaknesses and encourage more market-driven innovation.

How Should the United States Respond?

The report identifies a number of ways in which the United States can respond to China's state-directed science, technology, energy, and industrial development. These include:

- **Identification of core areas for priority investment and support:** Maintaining strategic advantage in core industries should be a priority of the United States. It encountered a similar challenge in the 1980s and 1990s as Japan grew and advanced in technological competitiveness. During that period, the United States identified core areas where it wanted to maintain competency and technological advantage. US government outlays on these projects were modest, but helped galvanize an effective private sector response.

  Current US strategy lacks a similar approach. The BRAIN initiative represents one example where the United States has provided significant funding to advance an area where it already possesses much academic and industry expertise, and which will have large technological benefits and positive spillovers to society. However, this plan is the exception rather than the rule. Other plans, such as the National Manufacturing Initiative, may be headed in the right direction, but their impact remains small compared to what is needed to keep the United States at the forefront.

  Part of the need is for adequate funding to these core industries, but an additional need is to adequately analyze and map the sectors in which the United States should maintain its competence. Two areas that might be particularly important going forward are advanced materials and sensors.

- **The United States defense S&T and industrial sectors are responding to China's rising technological challenge, but more needs to be done over the long term:** The US Third Offset Strategy and the Defense Innovation Initiative represent a belated recognition of the need to counter Chinese efforts to blunt US power projection capability. These efforts deserve to be supported with more investment and priority in policy attention throughout the remainder of the Obama administration and into the next administration and beyond.

  Such an offset strategy, if implemented consistently over time, holds the promise of eroding the effectiveness of Chinese counter-intervention systems, forcing China to either double-down on its investment in anti-access capabilities or seek a new approach. It also holds the potential to alter the decision-making calculus of the Chinese leadership, increasing markedly the cost of pursuing a strategy of maritime expansion and potentially rechanneling Chinese attention toward the Asian continent.

- **The United States can do a better job of protecting against unauthorized Chinese technology acquisitions.** These efforts should include both improved information security and updated technology transfer restrictions. Information security forms the first line of defense for US technology, and China has been able to steal critical information because of poor information security practices. Information security measures in both government and private industry should be strengthened. Industrial espionage on the scale that China has been conducting cannot and should not be isolated from the overall Sino-American relationship. US leaders must make it clear that the continuation of such activities, whether actively abetted or passively tolerated by the Chinese government, will have a tangible negative impact on the US–China relationship. The United States may have to take measures that will trigger Chinese retaliation. Absent such action, however, it is doubtful that the Chinese defense S&T sector will forgo the considerable benefits that accrue to it from stealing US technology.

Given the vital importance of information security and cybersecurity for the United States and China, the issue requires the attention and engagement of the highest levels of the two countries' leadership. One recommendation is that the US and Chinese presidents should be actively and personally engaged in meeting with each other to address concerns and find ways to forge robust and enforceable bilateral agreements to curb the most dangerous and egregious practices, in a similar approach to the US–Soviet nuclear arms control treaties during the Cold War.

Technology transfer restrictions also need to be updated, both to reflect the current international technology market and to maximize their effectiveness. Moreover, it is in the national interest of the United States for the government and private industry to work cooperatively to develop best practices and share threat information. To be effective, however, such measures should prioritize those technologies that are likely to provide the greatest battlefield edge in the future. In the defense and national security realm, this would include space and cyber capabilities, unmanned systems, high-speed propulsion, advanced aeronautics, autonomous systems, electromagnetic rail guns, and directed-energy systems.

INTRODUCTION

China has set its sights on becoming a global innovation powerhouse to bolster the country's economic competitiveness and safeguard its national security. While these endeavors began in the 1980s, adequate funding and sustained high-level leadership backing did not fully materialize until the beginning of the twenty-first century. The active involvement of the leadership elite in science, technology, and innovation (STI) development has been decisive in providing strategic vision and guidance, and helping to address implementation constraints, especially problems caused by a deeply fragmented innovation system.

One of the main policy instruments employed by the Chinese authorities to manage STI development is the use of plans that are conceived, funded, and managed by government agencies directed at areas deemed to be important for economic development, national security, and long-term science and technology (S&T) advancement. Around 100 S&T-related plans have been established over the past several decades, and they have played a vital role in supporting China's S&T development, especially in areas that have been overlooked or required additional state support.

While these plans have been responsible for many of the signature achievements in China's S&T development in recent years, such as the manned space plan and the building of the world's fastest supercomputer, they are also symptomatic of the weaknesses and inefficiencies of the Chinese STI system. A 2007 Organization for Economic Co-operation and Development (OECD) analysis of these S&T plans pointed out that they were conceived as policy tools "to overcome failures (market failures, learning traps, coordination problems) that affect research and development or more generally the innovation system."[1] It is usually much easier to establish a new plan than to attempt structural reforms to the STI system, which explains their proliferation. Moreover, once a plan is started, it is usually very difficult to close it down even if it has outlived its usefulness.

Consequently, the Chinese innovation system has evolved from a centralized, top-down apparatus into an increasingly ad hoc and fragmented structure where duplication is rampant, oversight is limited, and bureaucratic interests dominate over scientific needs. At the central government level alone, there are around 40 government agencies that are involved in the funding and management of S&T plans.

These structural defects became such a burden that in 2015 the Chinese authorities announced a far-reaching restructuring and consolidation of the civilian S&T plan framework. All plans would be vetted, and successful ones would be reorganized and merged into one of five programmatic categories. This overhaul is currently taking place and the goal is for completion by 2017.

This report examines, in Part 1, the current state of Chinese state-directed S&T development plans in the civilian, defense, and dual-use sectors and assesses, in Part 2, the near, medium, and long-term implications for US economic competitiveness and national security.

[1] Organization for Economic Co-operation and Development, *OECD Review of Innovation Policy: China* (Paris, France: OECD, 2008), 453.

Part I: Understanding Chinese State-Directed Strategies and Plans

Part 1 looks at the nature of the Chinese plans and strategies for defense, civilian, and dual-use S&T, energy, and other major industrial plans (Figure 1). The nature, importance, and influence of state-directed plans in China have undergone considerable evolution since the founding of the People's Republic of China in 1949. When the first plans were drawn up beginning with the First Five-Year Plan in 1953, the emphasis was on highly-centralized, orthodox socialist management that entailed detailed formulation and active state intervention. The Chinese term used to define these plans was 计划, or *jihua*. With economic liberalization and market reforms from the late 1970s onwards, the role and reach of the command economy steadily eroded, and so did the importance of centrally directed plans. The focus shifted to more indirect regulatory management and supervision.

In 2005, the Chinese authorities replaced 计划 with 规划, or *guihua*, which can be translated as either plan or 'program' but was intended to show that state approaches to planning would now be less interventionist and more hands-off and supervisory in nature.[2] Cong Cao, Richard Suttmeier, and Denis Simon offer another interpretation of the difference between these two terms. They argue that *guihua* "implies a strategic, comprehensive, and long-term development plan," while *jihua* "suggests contents and procedures for an action before its implementation."[3] 'Plan' remains the term that is most widely used in the translation of both *guihu*a and *jihu*a, so this report will follow standard convention.

Military Strategy and Defense and Dual-Use Research and Development Plans

This section covers a key selection of the most important and influential defense, civilian, and dual-use plans that the Chinese authorities are currently implementing. It also looks at some of the broad guidelines and strategies that provide the leadership and policy principles and long-term visions for the plans. To examine how China plans to meet this goal, this section links China's military strategy with its weapons acquisition process. It begins with a discussion of the current Military Strategic Guidelines and their role in shaping weapons acquisition, as well as possible modifications to the Guidelines and the implications for future weapons acquisition.

Discussion turns next to China's military and dual-use S&T plans, in particular its long-term Weapons and Equipment Development Strategy, the 2006–2020 Medium- and Long-Term Defense Science and Technology Development Plan (MLDP), the New High-Technology Weapons Plan (995 Plan), and the 863 High-Technology Research and Development Plan (863 Plan). The report identifies and describes the military platforms and capabilities China is investing in currently and over the long term based on these plans. It also identifies strategic dual-use industries relevant to national defense in which China intends to invest based on these plans and describes China's objectives for development in these industries.

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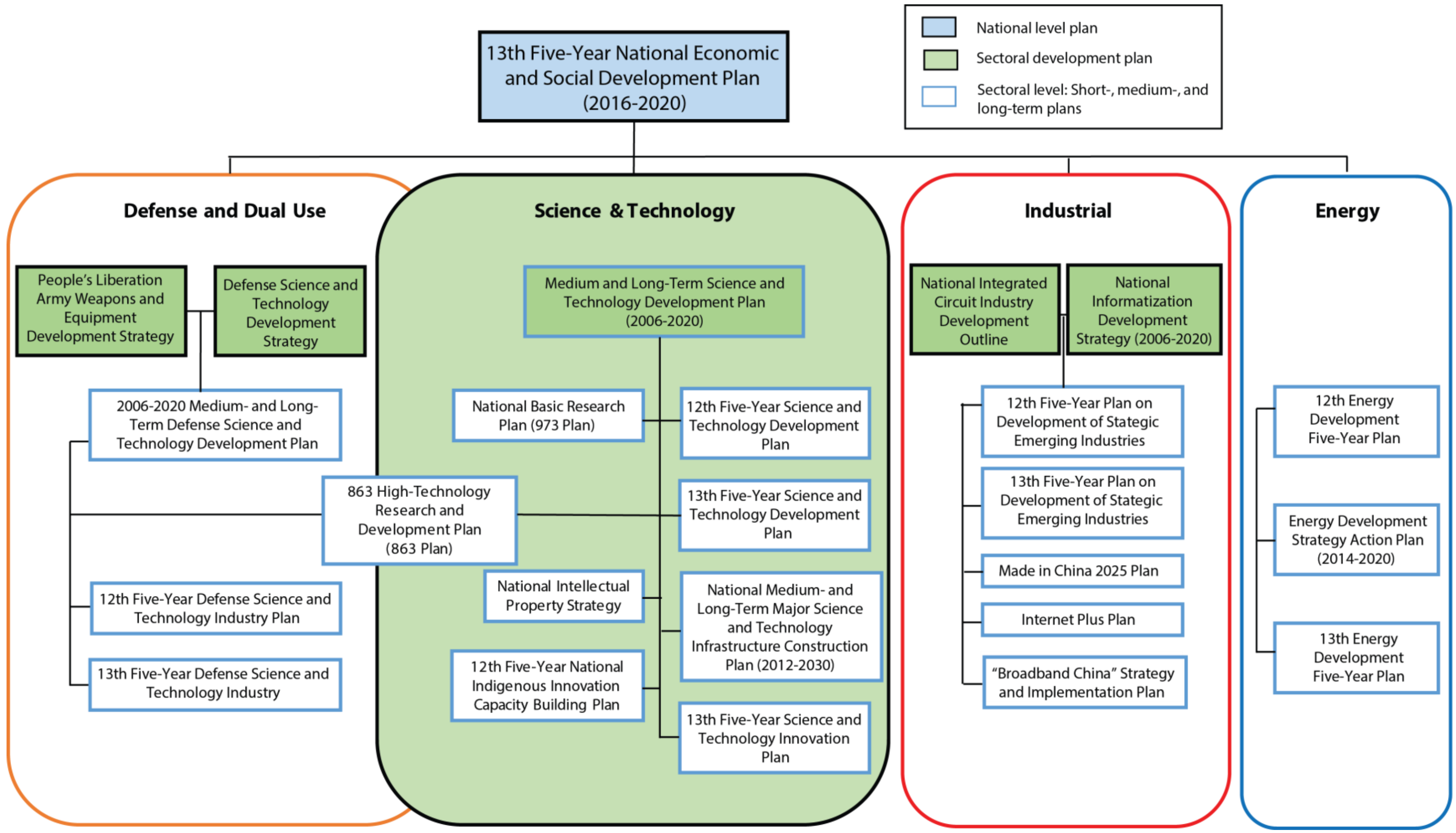
[2] "从计划到规划" [From *Jihua* to *Guihua*], 中国经济周刊 [*China Economic Weekly*], October 17, 2005, http://finance.sina.com.cn/review/20051017/00222036928.shtml.
[3] Cong Cao, Richard P. Suttmeier, and Denis Fred Simon, "China's 15-Year Science and Technology Plan," *Physics Today* (December 2006): 42, http://china-us.uoregon.edu/pdf/final%20print%20version.pdf.



Note: China's current S&T funding reforms will be consolidated in the 863 and 973 Plans. These reforms are ongoing, and as of early 2016, the new relationships with other plans are not clear.

Figure 1. China's state strategies and plans for science, technology, industrial, energy, and defense development

Civilian Science and Technology and Industrial Development Plans

The civilian S&T plans examined in this section can be sorted into two types: 1) regular S&T development plans including the Ministry of Science and Technology's Five-Year Plan for S&T Development and the S&T section under the Five-Year Guidelines for National Economic and Social Development; and 2) long-term S&T development plans such as the '973' National Basic Research Plan (973 Plan), the 2006–2020 Medium- and Long-Term Plan for Science and Technology Development (MLP), and the Strategic Emerging Industries (SEI) initiative. For this latter category, the report also assesses special policies and plans designed to promote priority areas under each plan, such as the sixteen megaprojects and seven strategic emerging industries. The report further details challenges and problems national-level S&T plans face, such as inefficient research funding mechanisms.

This section also assesses recent developments in national S&T planning that not only indicate new priorities but may also indicate deficiencies with legacy S&T plans. Of particular interest is the newly introduced "Made in China 2025" (中国制造 2025) with its focus on innovation, intellectual property, and green technology. Another new plan that is examined is the "Internet Plus" (互联网+) action plan, which will integrate mobile Internet, cloud computing, and the Internet of Things with modern manufacturing to encourage the development of e-commerce, industrial networks, and Internet banking. This section concludes with a look at the drivers, features, and implications of S&T funding and management system reforms that will establish a centralized S&T management platform and transform existing funding mechanisms into five new categories of S&T plans.

Energy Plans

This section provides a comprehensive overview of China's energy and industrial development plans, in particular, new energy technologies, China's urbanization plans, and other major industrial plans. China's overall energy strategy is governed by a "fundamental national policy" (*jiben guoce,* 基本国策) for energy efficiency and environmental protection. To increase overall efficiency within the energy market and reduce the burden of air pollution, state plans target increasing efficiency in both energy production and use and an improved energy mix that increases the ratio of natural gas, nuclear energy, and renewable energy sources.

To place current plans and initiatives in context, this study assesses the content and success of previous energy goals and conducts an analysis of trends in China's energy mix. Attention will also be paid to the political, economic, environmental, and security drivers behind these plans, including rising energy demands due to the demands of a wealthier, more urban society, the need to cap or limit energy growth due to lower levels of economic growth, the need to reduce air pollution and limit the impact of global warming, and China's desire to limit its dependence on foreign energy.

Energy-specific plans include China's 2014–2020 Climate Change Action Plan (2014–2020 国家应对气候变化规划); the 12th Five-Year Energy Development Plan (能源发展"十二五"规划, published in 2013), the Energy Development Strategy Action Plan (2014–2020) (能源发展战略行动计划, the Medium- and Long-term Development Plan for Renewable Energy in China (2007–2020) (可再生能源中长期发展规划), and the New Energy Vehicles Industry Development Plan (2012–2020) (节能与新能源汽车产业发展规划).

Broader S&T plans include the following: the 12th Five-Year Plan on Development of Strategic Emerging Industries ("十二五"国家战略性新兴产业发展规划, published in 2012), which includes energy saving and environmental protection, new energy (including nuclear, solar, wind, and bio-mass), and clean energy vehicles; Made in China 2025, which includes alternative energy among its focus technologies; China's 12th Five-Year Plan (2011–2015); and China's 13th Five-Year Plan (2016–2020).

Environmental plans include the 12th Five-Year Plan for the Environmental Health Work of National Environmental Protection (国家环境保护"十二五"环境与健康工作规划, published in 2011), the Action Plan for Air Pollution and Control (大气污染防治行动计划, published in 2013), and the legal framework itself. The Environmental Protection Law has been recently amended, with new provisions taking effect in January 2015, and the Air Pollution Law and the Air Pollution Law was amended in August 2015.[4]

This report outlines the implementation process for each plan and analyzes China's current progress and projections to reach the goals established in each. Attention is also given to areas where China's current policy framework is weak, such as monopolistic ownership structures (especially in oil and gas), and the use of pricing to encourage behavior change.

Urbanization Plans and Chinese Technology Acquisition Activities

A concise review is provided of China's urbanization plans, particularly the goals and strategies outlined in the National New-Type Urbanization Plan (2014–2020) (国家新型城镇化规划), which will facilitate the movement of an additional 100 million residents into cities by 2020. These goals are closely linked with China's overall energy goals and its ability to meet the structural, consumption, and health demands of increasingly larger urban areas.

A discussion of Chinese acquisition strategies for foreign technology and knowledge concludes the first part of the report. A particular focus is an examination of Chinese approaches of combining foreign and local technologies in new ways as well as absorbing and upgrading imported technology through what the Chinese term 're-innovation.' Other topics of focus include a look at Chinese catalogues for technology importation, and foreign technology requirements for civilian and defense plans.

Part II: Implications for US National Security and Economic Competitiveness

Part II of the report is devoted to assessing the implications of China's major state-directed plans for US economic competitiveness and national, especially military, security. It is divided into two sections.

Implications for US National Security

The first section undertakes a diagnostic net assessment of US strengths and weaknesses as compared with Chinese strengths and weaknesses, together with their economic, political, and military underpinnings. Particular attention is paid to identifying and describing in detail sectors in which China's plans for development may seek to erode US military superiority, as well as the military

[4] "China Passes Law to Control Air Pollution," Xinhua, August 29, 2015, http://news.xinhuanet.com/english/2015-08/29/c_134568483.htm.

platforms and capabilities in which China intends to invest based upon these plans. The report identifies strategic industries relevant to national defense in which China intends to invest and describes China's objectives for developing these industries. The report also provides examples of specific hardware investments by China and assesses the implications of such investments for the US military.

Implications for US Economic Competitiveness

The implications for US economic competitiveness from China's civilian state plans are addressed in this section, beginning with an examination of the underlying principles and policy instruments that shape the nature and guide the implementation of key state plans in the technology, industrial, and energy domains. Techno-national opportunism and indigenous innovation are two core values that are explored in detail. These principles are reflected in a number of policy instruments used in the implementation of the state plans:

1. protectionism;
2. the cultivation of industrial champions;
3. trading market access for technology transfers;
4. employment of state catalogues to regulate investment and technology imports;
5. the promotion of Chinese technology standards; and
6. an ambitious strategy to open up foreign markets for Chinese products as well as to secure energy and other critical supplies.

To gauge the current and long-term potential impact of Chinese state plans on US economic competitiveness at a more detailed level, a series of eleven case studies have been conducted that are concentrated in four sectors:

1. **Information and communications technology**, which covers 5G technology, cloud computing, global navigation satellite systems, and integrated circuits;
2. **Manufacturing,** which includes additive manufacturing, advanced robotics, and nanomaterials;
3. **Transportation,** which covers electric vehicles and high speed rail; and
4. **Medical and healthcare**, which covers biopharmaceuticals and medical devices.

The study turns next to the risks and opportunities for US firms operating in the energy industry. One of the biggest worries for US companies is that Chinese indigenous innovation strategies are central to their energy development plans. China will also be a growing international competitor on global energy markets. As to opportunities, the China energy market offers a wealth of prospects that include safety and monitoring, gas turbines, electricity storage, energy efficiency, power grid management, oil and gas, and solar energy.

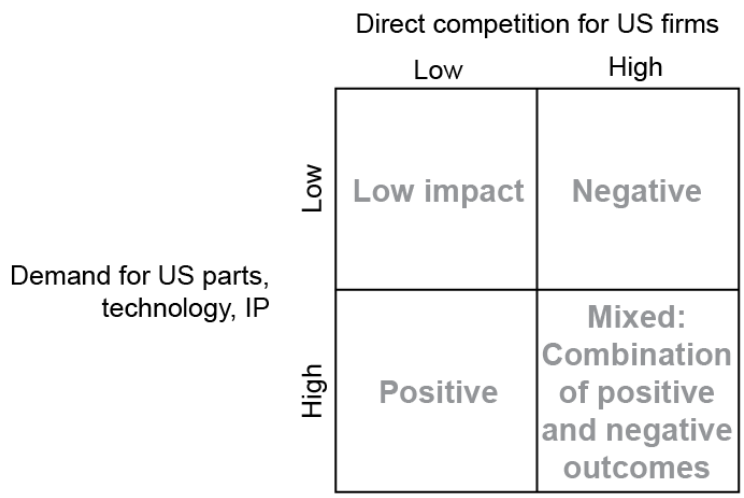
Analytical Framework for Assessing Impact on US Economic Competitiveness

A general analytical framework has been developed in regard to the case studies to facilitate comparisons across industries and examine the impact of the sectoral case studies on US economic competitiveness, especially on the labor market. In looking at the critical factors that shape how US and Chinese companies compete, collaborate, and interact in their own markets, in each other's markets, or more globally, the framework is focused on three components: 1) technology levels and trajectories of US and Chinese firms; 2) industry market conditions; and 3) government policy measures.

These components then feed into a discussion of the implications of US economic competitiveness. A simple, but clear, methodology is employed to assess the outcomes, actual and potential, on the United States. Based on the discussion of technology levels, market conditions, and government policy measures, approximate levels of direct competition for US firms and demand for US parts, technology, and intellectual property are assigned to each industry for three periods: the present, short to medium term, and long term. These are assigned on a scale from low to high. Using an outcomes matrix with these two variables as axes, the implications for economic competitiveness are determined to be either low impact, positive, negative, or mixed (Figure 2).

A complete explanation of the framework is provided in Part II, Section B on implications for US economic competitiveness.

Figure 2. Matrix of possible effects of Chinese industries on US competitiveness



The Current State of Academic and Policy Analysis of China's S&T Policies and Progress

The Chinese and Western literature on China's engagement in STI is limited but has been growing quickly in the past few years and comes from four main sources that shape the nature of the analysis: academia, policy-oriented research institutions, researchers and research outfits affiliated with the business community, and independent analysts. Policy think tanks and business-affiliated outlets have been the most active and high-profile, while academic research has tended to lag behind.

This scholarship on Chinese STI can be sorted into at least two categories: 1) studies that examine the nuts and bolts of Chinese STI development; and 2) assessments of the impact that China's STI progress is having on the outside world, at the international, national, sectoral, or corporate level. The first category is primarily descriptive in nature while the second group is both descriptive and prescriptive.

As China's STI development is complex, wide-ranging, and far from transparent, it is not surprising that there are considerable differences in assessments of how successful or not it has been, and whether China's technological catching up represents a source of concern, if not outright threat, to the United States and the rest of the world. There are analysts who view China as catching up with the United States and laud its expansion of market size, R&D expenditure, and product development. They urge action by the United States to develop better policies that support R&D for commercialization in new technologies, which will in turn create jobs and new drivers of the US economy.[5] Others highlight the inefficiencies of China's innovation system, citing the low quality of research output, lack of original innovations, institutional problems, misconduct, corruption, and a lagging education system These may result in the failure of China to deliver—or at least to stall—on its goal to become an innovation powerhouse. Even with these obstacles, however, China will still steadily rise in its global leadership, attract increasing international attention, and be an appealing global partner in research and innovation.[6]

Policy Think Tanks and Business-Affiliated Assessments

A small but vocal group of US analysts have emerged in the past few years to argue that China's S&T policies, especially its push for indigenous innovation, represent a major challenge to US economic and business interests and should be disputed. In a 2010 report sponsored by the US Chamber of Commerce, James McGregor wrote that China's indigenous innovation strategy discriminates against foreign companies and will increase economic and political tensions between China and other countries as it distorts global innovation and markets. The policy further shifts China towards techno-nationalism and away from openness and international cooperation. Indeed, indigenous innovation policies, and others contained in the MLP, support patent rules, product testing and approval regimes, government procurement policies, and industry and technology standards that delay or block the introduction of foreign imports, increase market barriers to foreign technology, support domestic retaliation against foreign companies on intellectual property rights (IPR), and give privileged status to state-industrial monopolies.[7]

Robert Atkinson, the founder and head of the Information Technology and Innovation Foundation based in Washington, D.C., argues that China practices economic mercantilism through its innovation policy and seeks absolute advantage in global competition to ensure that Chinese-owned firms win. Atkinson asserts that these mercantilist policies unfairly aid China's domestic economy at the expense of the global economy, causing conflicts between US and Chinese workers and companies.[8] These protectionist policies by China have only increased over the past few years as Xi Jinping has come to power, in what Atkinson refers to as "indigenous innovation on steroids."[9]

[5] Milton Kotler, "Sino-US Technology Marathon and Implications for the US," *International Journal of China Marketing* 1 (2010): 31–44, http://www.na-businesspress.com/ijcm/MKotlerWeb.pdf.
[6] Micah Springut, Stephen Schlaikjer, and David Chen, "China's Program for Science and Technology Modernization: Implications for American Competitiveness," U.S.-China Economic and Security Review Commission, January 2011, http://origin.www.uscc.gov/sites/default/files/Research/USCC_REPORT_China's_Program_forScience_and_Technology_Modernization.pdf.
[7] James McGregor, "China's Drive for 'Indigenous Innovation': A Web of Industrial Priorities," US Chamber of Commerce, 2010, https://www.uschamber.com/sites/default/files/legacy/reports/100728chinareport_0.pdf.
[8] Robert D. Atkinson, "Enough is Enough: Confronting Chinese Innovation Mercantilism," Information Technology and Innovation Foundation, February 2012, http://www2.itif.org/2012-enough-enough-chinese-mercantilism.pdf.
[9] Author interview with Robert D. Atkinson, October 14, 2015.

The US-China Business Council (USCBC), a private business-backed organization that advocates for US-China trade, finds similar protectionist policies in a 2013 report on China's SEI policy. The report argued that the SEI initiative limits opportunities for foreign companies and increases unfair competition. Concerns raised in the USCBC report include product and technology catalogues, discriminatory criteria for IP qualification, government procurement, policy transparency, and localization requirements.[10] The Commission on the Theft of American Intellectual Property (IP Commission), an independent and bipartisan initiative of leaders in private sector, government, and academia, stated in its 2013 report that China is the leader in international IP theft, which generates negative effects on the US economy, including job losses, slowdown of US GDP growth, and diminishing incentives for innovation.[11]

The policy solutions provided by these reports emphasize the need for the US government and companies to actively confront the challenges and opportunities posed by China's innovation policies. These range from broad suggestions of increasing political confrontation and protracted trade disputes to more specific actions such as pressuring China through the US Trade Representative's Office or global institutions such as the World Trade Organization, and possibly forming a new alliance of free-trading nations.[12] On the IP issue, the IP Commission recommended that the US government investigate and prosecute cases related to IP theft in the short term, build a more sustainable legal framework in the medium term, and build institutions to conduct further IP protection in the long term.[13] Actions to take advantage of opportunities include working with China to prevent techno-nationalistic and protectionism tendencies, and to encourage foreign companies to bring advanced technology and become trusted partners.[14]

Academic Assessments

Academic assessments of China's S&T plans are few but tend to take a cautionary position on its S&T policies and question China's chances of successfully implementing the plans. In an assessment of the MLP, China scholars Cong Cao, Richard Suttmeier, and Fred Simon note that the plan is characterized by the central government's identification of priority projects and the mobilization of resources to work toward these projects to ensure the country's long-term competitiveness. They cast doubt, however, on whether the MLP gives appropriate balance to indigenous innovation efforts versus global technology flows and whether the Chinese government will be able to efficiently allocate the substantial funding earmarked for large national projects.[15]

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[10] US–China Business Council, "China's Strategic Emerging Industries: Policy, Implementation, Challenges, and Recommendations," March 2013, https://www.uschina.org/sites/default/files/sei-report.pdf.
[11] The Commission on the Theft of American Intellectual Property, "The IP Commission Report: The Report of the Commission on the Theft of American Intellectual Property," May 2013, http://www.ipcommission.org/report/ip_commission_report_052213.pdf.
[12] See Atkinson, "Enough is Enough"; McGregor, "China's Drive"; Philip I. Levy, "China's Indigenous Innovation Policy and US Interests," written testimony for House Committee on Foreign Affairs Subcommittee on Terrorism, Nonproliferation, and Trade, March 9, 2011, http://www.aei.org/wp-content/uploads/2011/10/20110309-Levy.pdf.
[13] "The IP Commission Report: The Report of the Commission on the Theft of American Intellectual Property."
[14] Sylvia Schwaag Serger and Magnus Breidne, "China's Fifteen-Year Plan for Science and Technology: An Assessment," *Asia Policy* 4 (2007): 135−64, http://www.stratresearch.se/Documents/Omvärldsdokument/Om%20Kinas%2015 percent20Kinas percent2015-årsplan.pdf; Guangyu Li and Jonathan Woetzel, "What China's Five-Year Plan Means for Business," McKinsey & Company, July 2011, http://www.mckinsey.com/insights/economic_studies/what_chinas_five-year_plan_means_for_business.
[15] Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan."

A useful assessment of Chinese innovation policies by Feng-chao Liu, Denis Fred Simon, Yu-tao Sun, and Cong Cao examines the diverse array of state STI policies, of which the state-directed plans are just one, albeit the most important, sub-set. Other policy mechanisms include laws, trade catalogues, financial, tax, fiscal, and industrial policies issued by different levels of the state, including the National People's Congress, State Council, and government ministries. The authors point out that when the MLP was passed in 2006, 79 related policies accompanied the plan, covering specific S&T, industrial policy, and financial and tax issues. An important positive trend in the issuance of these policies over the past few decades is that they have begun to evolve from a compartmentalized model in which they are drafted and approved by single agencies to a more collaborative approach in which two or more agencies jointly issue them.[16]

Stephen Roach, a senior fellow at Yale University and former chairman of Morgan Stanley Asia and chief economist at Morgan Stanley, calls China's 12th FYP and SEI initiative the third watershed event in the development of modern China, and warns of potential tension between China and the United States due to an asymmetrical rebalancing scenario. As China shifts toward private consumption and reduces its foreign exchange reserves and its demand for dollar-denominated assets, the United States will need to come up with new sources of funding or secure its external funding with a weaker dollar and/or a rise in real long-term interest rates.[17]

Other scholars believe that the emergence of a vibrant and capable Chinese innovation system presents opportunities for the international community. Sylvia Schwaag Serger and Magnus Breidne, researchers at the Swedish Institute for Growth Policy Studies, acknowledge that the MLP demonstrates a commitment in China to state-promoted innovation but cite many positive spillover effects to other countries from China's increased R&D. These include increased opportunities for mutually beneficial international cooperation in research and education as well as through increased trade.[18]

These liberalist international views of the positive opportunities of cooperation arising from China's technological rise are shared by many analysts in the business community. A McKinsey report by Guangyu Li and Jonathan Woetzel analyzes the effects of China's FYP for foreign companies. Opportunities identified include: 1) market potential for domestic and foreign companies; 2) deregulation of education, financial services, health care, and logistics; and 3) opportunities for companies with advanced technology where foreign players can merge and acquire local companies to become more competitive in China's domestic markets.[19] Li and Woetzel conclude that China is still catching up globally in science-based innovation, but it has already built a strong foundation. They believe that China will continue to promote innovation by empowering entrepre-

[16] Feng-chao Liu, Denis Fred Simon, Yu-tao Sun, and Cong Cao, "China's Innovation Policies: Evolution, Institutional Structure, and Trajectory," *Research Policy* 40, No. 7 (2011): 917–31.
[17] Stephen S. Roach, "China's 12th Five-Year Plan," Morgan Stanley, April 2011, http://www.law.yale.edu/documents/pdf/cbl/China_12th_Five_Year_Plan.pdf.
[18] Schwaag Serger and Breidne, "China's Fifteen-Year Plan for Science and Technology."
[19] Guangyu Li and Jonathan Woetzel, "What China's Five-Year Plan Means for Business."

neurs, allowing markets to work (with government acting as a demanding customer), and strengthening China's innovation clusters. Global companies can benefit from the Chinese innovation model and compete locally by beating, buying, or joining with local Chinese companies.[20]

International Assessments

While US analysts tend to be warier of China's technological rise, views from Europe and the international community appear to be more welcoming and win-win in nature. The OECD sees China as contributing to solve energy, natural resources, and environmental problems, and to increased global competition that will have a positive impact on long-term global innovation.[21] A European Union (EU) report refers to common interests with China in areas such as food, agriculture, biotechnologies, sustainable urbanization, aviation and aeronautics, and ICT. Additionally, cooperation in human capital movements and joint research centers could provide opportunities for EU higher education and research establishments.[22]

The Europe China Research and Advice Network, a three-year project funded by the EU, argues that urbanization and infrastructure development increase commercial opportunities for the EU in inland China and less developed cities. These opportunities are expected to come in industrial sectors such as advanced environmental technology but will not extend to strategic sectors.[23] Nesta, an independent charity that works to increase innovation capacity in the UK, argues that China remains an absorptive state and that the expansion in its research base has not yet brought about significant improvements in the quality of research output. However, it also recognizes the increasing global visibility of Chinese multinationals, the positive contribution to China's growth resulting from Chinese companies' adeptness in incremental re-innovation, and the diverse models of innovation within China. It concludes that "the greatest 'China risk' for innovative companies is focusing too heavily on downside risks, and missing out on the opportunities that China presents."[24]

[20] Jonathan Woetzel, Yougang Chen, James Manyika, Erik Roth, Jeongmin Seong, and Jason Lee, "The China Effect on Global Innovation," McKinsey Global Institute Research Bulletin, July 2015, http://www.mckinsey.com/insights/strategy/chinas_innovation_imperative. See also full McKinsey report: Jonathan Woetzel et al., "The China Effect on Global Innovation," McKinsey Global Institute, October 2015.
[21] OECD and Ministry of Science and Technology, "OECD Reviews of Innovation Policy China, Synthesis Report," 2007, http://www.oecd.org/sti/inno/39177453.pdf.
[22] Sociedade Portuguesa de Inovacao, United Nations University, and Austrian Institute of Technology, "Science, Technology and Innovation (STI) Performance of China D9: Final Report," European Union, July 2014, http://eeas.europa.eu/delegations/china/documents/eu_china/research_innovation/4_innovation/sti_china_study_full_report.pdf.
[23] Robert Ash, Robin Porter, and Tim Summers, "China, the EU, and China's Twelfth Five-Year Programme," Europe China Research and Advice Network, 2012, http://eeas.europa.eu/china/docs/division_ecran/ecran_china_the_eu_and_china_s_twelfth_five_year_programme_ash_porter_summers_en.pdf.
[24] Kirsten Bound, Tom Saunders, James Wilsdon, and Jonathan Adams, "China's Absorptive State: Research, Innovation, and the Prospects for China-UK Collaboration," Nesta, October 2013, http://www.nesta.org.uk/sites/default/files/chinas_absorptive_state_0.pdf.

Chinese Assessments

Chinese researchers have a similar mix of criticism and praise for China's S&T policies and plans. Most Chinese scholars highlight the progress China has made toward its STI goals. A report by Sichuan University researchers Chen Xuanjin, Wang Yuandi, and Qu Xihua cites the MLP as the key driving force behind China's recent enhanced global and technological competitiveness. The plan has helped to increase R&D investment, the number of full-time researchers, and the number of published articles and patents.[25] Long Guoqiang, deputy director of the State Council Development Research Center (DRC), a leading government think tank, believes China has a unique advantage to carry out STI through its large domestic and industrial markets and its comparative advantage in S&T human capital. Long argues that the Made in China 2025 and Internet Plus plans will further accelerate China's scientific and technological innovation.[26]

Leading Chinese innovation scholar Mu Rongping of the Institute of Policy and Management at the Chinese Academy of Sciences (CAS) states that the Chinese government has enhanced its support for innovation in recent years by providing favorable policies to domestic and foreign companies in China. However, Mu notes that there are still barriers to entry for Chinese firms, especially in some high-tech areas. This will constrain and challenge China as it seeks to further improve its global competitiveness.[27] Lü Tie and He Jun of the Institute of Industrial Economics at the Chinese Academy of Social Sciences (CASS) estimate that to accelerate the integration of foreign S&T resources, more Chinese firms will need to establish overseas R&D facilities and acquire foreign companies during the 13th Five-Year Plan.[28]

Despite China's steady progress in improving its technological capacity, Chinese scholars and researchers do not believe that China will catch up with advanced countries, particularly with the United States in the near future. Wei Jigang, a researcher at the DRC, argues that China is not competitive globally in high-end manufacturing and has only limited competitiveness in the telecommunication, equipment manufacturing, petrochemical, and automobile industries, despite having a small but growing number of firms emerging as leaders, such as Huawei in the telecommunications domain. This limited competitiveness is caused by a poor innovation structure, weak capabilities in indigenous innovation, a low industrial concentration rate, and a high degree of foreign control in some areas.[29]

[25] Chen Xuanjin, Wang Yuandi, and Qu Xihua, "自主创新政策实施背景下中国科技面貌的国际比较" [Comparison of Scientific Outlook Between China and Developed Countries Under the Background of Indigenous Innovation], 科技管理研究 [*Science and Technology Management Researc*h] (2014/13): 20–25.

[26] Long Guoqiang, "全球新一轮科技创新风起云涌" [The New Round of Global Technological Innovation], 中国政府网 [www.gov.cn], May 22, 2015, http://www.gov.cn/zhengce/2015-05/22/content_2866560.htm.

[27] Jia Jingfeng, "中科院科技政策所长: 中国科技出海机遇挑战并存" [Director of the CAS Institute of Policy and Management: Chinese Technology Faces Both Opportunities and Challenges in Global], 中国新闻网 [Chinanews.com], July 14, 2012, http://www.chinanews.com/cj/2012/07-14/4032359.shtml.

[28] Lu Tie and He Jun, ""十三五"中国工业发展的新形势与政策调整" ["13th Five-Year" New Situation and Policy Adjustment for China's Industrial Development], 学习与探索 [*Study and Exploration*] (2015/6): 81.

[29] Wei Jigang, "我国重点产业发展和竞争力状况及政策建议" [Development and Competitiveness of China's Key Industries and Policy Recommendations], 发展研究 [*Development Research*] (2010/10): 72.

Another senior Chinese scholar who is critical of that government's S&T development plans is Huang Qunhui, director of the CASS Institute of Industrial Economics. Huang claims that Made in China 2025 does not address the fundamental question of identifying China's core competencies as a manufacturing power. The plan also ignores the importance of improving productivity for the whole manufacturing sector. Huang's conclusion is that the plan is simply a replica of traditional industrial policies with a greater intensity of policy support and longer planning periods.[30]

[30] Jin Hui, "社科院专家谈中国制造 2025: 提升国际竞争力" [Experts from Chinese Academy of Social Sciences Talked about "Made in China 2025": Enhance Global Competitiveness], 新浪财经 [finance.sina.com], August 5, 2015, http://finance.sina.com.cn/china/20150805/005922875945.shtml.

PART I

UNDERSTANDING CHINESE STATE STRATEGIES AND PLANS

A. MILITARY STRATEGY AND DEFENSE AND DUAL-USE SCIENCE AND TECHNOLOGY DEVELOPMENT PLANS AND STRATEGIES

The modernization of China's defense science, technology, and industrial base is a pressing priority for the Chinese authorities in the face of an increasingly complex external security environment and the PLA's ever-growing technological demands. With abundant funding available, a major challenge for the relatively young and inexperienced armament community is to successfully guide the long-term transformation of the country's military technological capabilities.

A critical instrument in managing this process is the formulation and implementation of a comprehensive set of defense and civil-military dual-use science and technology research, development, and acquisition strategies and plans (Figure 3). This section looks at the most important of these plans and strategies:[31]

- The PLA's Weapons and Equipment Development Strategy (WEDS, 武器装备发展战略) and long-, medium-, and short-term Weapons and Equipment Construction Plans (WECP, 武器装备建设规划/计划)
- The 863 High-Technology Research and Development Plan (高技术研究发展计划）
- The 995 High-Technology Development Plan (高新工程)
- The 2006−2020 Medium- and Long-Term Defense Science and Technology Development Plan (MLDP, 国防科技工业中长期科学和技术发展规划)

The WEDS and WECP represent the regular weapons and equipment research, development, and acquisition process while the 863, 995, and MLDP are special plans to address specific capabilities requiring additional attention and support.

The Relationship Between China's National Military Strategy and Its Defense Science and Technology Strategies and Plans

To understand the rationales, activities, and goals of these strategies and plans, it is necessary to examine the strategic and organizational context behind their formulation. From an organizational perspective, these S&T strategies and plans are closely tied and subordinate to the country's national-level military strategy, which is known as the Military Strategic Guidelines (MSG). The MSG comprises "the overall principles (总原则) and guiding principles (总纲领) for planning and guiding the development and utilization of the armed forces."[32] The Central Military Commission (CMC) is responsible for the formulation and issuance of the MSG, which is carried out in coordination with other PLA departments.[33]

[31] There are a handful of other S&T plans and programs, such as the 973 and SEI programs, that have military and/or dual-use-related activities, but they are much smaller in scale and impact compared to the four strategies, programs, and plans discussed here.
[32] PLA National Defense University Army Building Research Department, *Study Guide for Jiang Zemin Thought on National Defense and Army Building* [江泽民国防和军队建设思想学习读本], 2nd ed. (Beijing: Chinese Communist Party History Publishing House, April 2004), 56–67.
[33] On the process for this, see Zhang Wannian writing team, 张万年传 [*Biography of Zhang Wannian*] (Beijing: Liberation Army Press, 2011), 59−72.

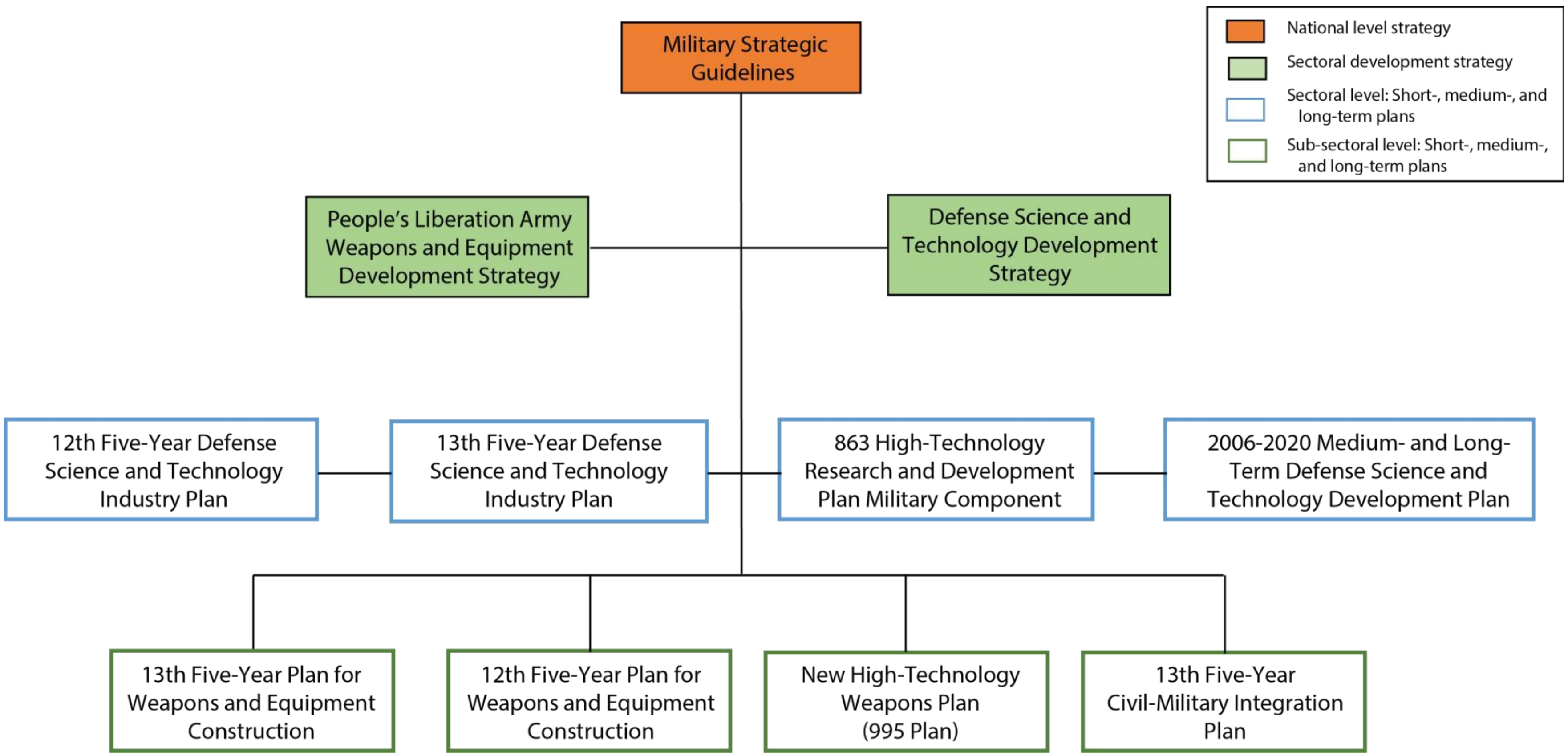

Figure 3. China's state strategies and plans for defense and dual-use development

Although the MSG is classified, a number of published official documents and academic studies shed useful insights into its likely contents, especially as it relates to defense S&T requirements.[34] The 2015 defense white paper offers the most detailed and authoritative discussion of the MSG that has been released by the Chinese military authorities.[35] This white paper is titled "China's Military Strategy" (hereafter referred to as the 2015 Military Strategy) and points to a significant revision to the country's military strategy that emphasizes preparation for maritime conflict, information-era warfare, and the prioritization of the oceans, outer space, and cyberspace as the new "critical security domains."

The 2015 Military Strategy provides an assessment of the global strategic environment that highlights several significant technological trends. The first is that the global revolution in military affairs is at a new stage and is "posing new and severe challenges to China's military security." Of particular concern is the threat from long-range, precise, smart, stealthy, and unmanned weapons. A second feature of the rapidly evolving technological landscape is the emergence of new domains, of which outer space and cyber-space are emphasized as the "new commanding heights in strategic competition." A third accelerating trend is a fundamental change in the nature of warfare towards informationization, which refers to the information age and the rise of information-related processes and capabilities. The 2015 Military Strategy points out that it is the "major powers"—primarily referring to the United States, but also including other countries such as Russia—that are in the vanguard of this process and are "speeding up their military transformation and force restructuring."

The impact of informationization is deemed to be so profound that the new military strategy has adjusted its definition of the nature of future warfare that the PLA should be preparing to fight and win from "local wars under conditions of informationization," which has been the guiding formulation since 2003, to winning "informationized local wars." PLA analysts say that this is a significant revision in terminology because the role of informatization has been elevated from being important to becoming the dominant factor.[36]

The 2015 Military Strategy points out that a key goal of informationized warfare is to gain information dominance through the building of systems of systems, especially focused on a number of capabilities:

- Better utilization of information resources
- Strengthening reconnaissance, early-warning, and command and control systems
- Development of medium- and long-range precision strike capabilities
- Improving comprehensive support systems

[34] David M. Finkelstein, "China's National Military Strategy: An Overview of the 'Military Strategic Guidelines'," in *Right Sizing the People's Liberation Army: Exploring the Contours of China's Military,* eds. Roy Kamphausen and Andrew Scobell (Carlisle, PA: Army War College, 2007), 67–140.
[35] State Council Information Office, "China's Military Strategy," May 25, 2015.
[36] Wen Bing, "Correctly Locate the Basic Point for Preparation for Military Struggle," *Study Times* [学习时报] 8 (July 2015).

Moreover, the 2015 Military Strategy stresses the importance of "maritime military struggle" in future preparations for military struggle. This signals that the PLA Navy now stands at the top of priorities among the service arms. There is also an important change in naval strategy that adds "open seas protection" (远海护卫) to the list of the PLA Navy's chief missions alongside its traditional "offshore defense" strategy. By comparison, the 2010 and 2013 defense white papers had only mentioned that the PLA Navy was developing "open sea" capabilities.[37]

The 2015 Military Strategy offers a general framework of the modernization requirements of the PLA's service arms:

- The ground forces are shifting from theater defense to a more mobile transregional role, especially through the building of multi-functional and modular units that are able to engage in joint and trans-theater operations.
- The navy is expanding its missions from "offshore defense" to "open seas protection," which requires the building of capabilities for "strategic deterrence and counterattack, maritime maneuvers, joint operations at sea, comprehensive defense, and comprehensive support."
- The air force is turning from a traditional focus on territorial air defense to also emphasizing offensive operations and building an air-space force structure geared towards informationized operations, which includes strategic early warning, information countermeasures, airborne operations, and strategic projection.
- The Second Artillery is strengthening its nuclear offense capabilities to be better able to conduct deterrence and counterstrike operations as well as building up conventional medium- and long-range precision strike missile capabilities.

The section termed 'military force building' (军事力量建设) in the 2015 Military Strategy is concerned with modernization and reform issues, which includes consideration of defense S&T matters.[38] There is a brief discussion on armament development in which the document points out that "China's armed forces will speed up the upgrading of weaponry and equipment, and work to develop a weaponry and equipment system that can effectively respond to informationized warfare and help fulfill the missions and tasks." The military strategy adds that particular emphasis will be placed on information dominance, systems building, and indigenous innovation.

The PLA's Weapons and Equipment Development Strategy and Construction Plans

While the MSG provides broad strategic principles and general guidelines on weapons requirements and acquisition issues, the detailed nuts and bolts of programmatic management, strategic design, planning, and implementation is contained in the supporting WEDS and WECP. These planning documents represent the long-term vision and roadmap for implementation of the Chinese defense establishment's S&T development for its weapons and equipment capabilities. Not surprisingly, they are classified, and there are only occasional references as to their role and importance in guiding the PLA's technological modernization. However, in an article marking the

[37] State Council Information Office, *The Diversified Employment of China's Armed Forces* (Beijing, April 2013) and State Council Information Office, *China's National Defense in 2010* (Beijing, March 2011).
[38] The equivalent section in the MSG is termed 'army building' [军队建设].

end of the General Armament Department (GAD) as part of the restructuring of the PLA high command at the end of 2015, the *China Military Industry News* (中国军工报), the GAD's news mouthpiece, disclosed for the first time that one of its accomplishments was to establish "scientific planning of long-term defense science and technology and weapons and equipment development through a 20-year development strategy, 10-year construction outline, and 3 five-year plans."[39]

The WEDS provides the overall strategic rationale for the country's armament development. It offers long-term planning stability for 10 to 20 years and provides an integrated approach involving input from across the entire defense establishment. Moreover, it is a rigorous assessment that looks at regional and global strategic, military, and technological trends, and the nature of future war and compares these with China's national and military economic, industrial, and technological capabilities to support armament research and development. As one PLA study noted,

> In the formulation of military equipment development plans, it is necessary to use a military equipment development strategy as their foundation. Chiefly, this means considering the country's situation for a relatively long period of time in the future, and the country's military strategy policies, as well as analyzing and making predictions for the international strategic environment, the security environment on the country's periphery, and the military equipment needs of the country's troops in future military conflicts.[40]

The WEDS comes in two categories: a national-level version and service-level variants. The national-level WEDS is produced by the PLA General Armament Department and is a comprehensive and integrated strategy for the PLA and defense S&T establishment. This WEDS is described as "subordinate to and serves" the MSG and also takes into account the country's national development strategy and the MLP.[41]

The national-level WEDS appears to have been first introduced in the beginning of the 2000s, unlike the MSG with origins dating back to the 1950s. An article in the PLA's official media mouthpiece the *Liberation Army Daily* in October 2002 on weapons modernization mentioned that the PLA was in the process of implementing a "weapons and equipment development strategy" along with the 2000–2005 10th Five-Year "Weapons Construction Plan" (装备建设计划) that had been formulated by the CMC and PLA general headquarters.[42]

A major reason why the PLA was a latecomer in putting together an overarching weapons development strategy is that it did not establish a unified and high-level armament decision-making and policy planning system until the formation of the GAD in 1998. Prior to the GAD's creation, the Commission for Science, Technology, and Industry for National Defense (COSTIND) was in charge of the defense S&T portfolio. It had devised a long-range defense S&T strategic roadmap in 1986 entitled "China's Defense Science and Technology to 2000." This strategic guidance was

[39] "For Seventeen Years, We Walked Together," 中国军工报 [*China Military Industry News*], December 31, 2015.
[40] 军事装备学 [*The Study of Military Equipment*] (Beijing: National Defense University Press, 2000), chap. 9.
[41] Fu Guangming and Ji Hongtao, "Exploration of Hu Jintao's Strategic Thinking on Strengthening Military with Science and Technology," 中国军事科学 [*China Military Science*] 5 (2011).
[42] Liu Cheng, "Creating a New Situation in the Weapons and Equipment Modernization Effort," 解放军报 [*Liberation Army Daily*], October 14, 2002.

much longer than the WEDS and was a consensus document reflecting the input of more than 2,000 military and civilian experts.[43]

PLA service arms also formulate their own WEDS that are specifically designed to address their own service requirements. The PLA Navy appears to have been the first service to develop a WEDS, in the mid-1980s. This was due to the influence of its commander at the time, Admiral Liu Huaqing, who was a strong advocate of long-term armaments planning.[44] A major source of tension exists between the national and service WEDS. The national WEDS is aimed at encouraging joint service cooperation while the service versions are engaged in inter-service competition for funding and project approval.

The WECP is responsible for the implementation of the strategic requirements and tasks that are set out in the WEDS. There are different versions of the WECP based upon duration (ten, five, or one year) and organizational level (national or service arm). At the pinnacle is the national-level Long-term Weapons and Equipment Construction Plan (LWECP) that extends over a 10-year planning period and covers the entire defense establishment. This plan is:

> primarily used to direct the formulation of military equipment development plans and the implementation process of significant policy decisions and to indirectly guide specific management actions. The [long-term] military equipment development plan holds a dominant position among military equipment development plans: that of the foundation of other military development planning work.[45]

The LWECP is regularly adjusted and updated.

Operational implementation is carried out by a five-year Medium-Term Weapons and Equipment Construction Plan (MWECP) and a one-year Short-Term Weapons and Equipment Construction Plan (SWECP). The MWECP parallels the five-year planning cycle that the PLA and Chinese economy practices, which means that the current 12th FYP will be replaced with a 13th edition in 2016. The MWECP is responsible for the direct formulation and guidance of defense S&T-related research, development, acquisition, maintenance, and resource allocations, while the SWECP is a detailed implementation plan focused on specific projects.

The Chinese military authorities are tightly guarded over the contents of these armament strategies and plans, but occasionally do offer broad hints about their general principles. In an article in the GAD's main newspaper shortly after the accession of Xi Jinping as the country's paramount leader in late 2012, Executive Deputy GAD Director Lt-Gen. Li Andong, a prime architect of the armament modernization effort between the early 2000s and mid-2010s, talked about the need to strengthen the strategic guidance for the country's armament building.[46] Li highlighted a number of key points:

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[43] Yan Xin, ed., 中国当代国防科技发展概况 (—) [*Overview of the Development of China's Contemporary Defense Science and Technology,* Part 1] (Academic Video Publishing House, 2004), 168–70.
[44] 刘华清回忆录 [*Memoirs of Liu Huaqing*] (Beijing: Liberation Army Press, 2004), chap. 17.
[45] *The Study of Military Equipment*, chap. 9.
[46] Li Andong, "Implement the Scientific Development Concept, Strengthen the Strategic Direction of Armament Building," 中国军工报 [*China Military Industry News*], December 5, 2012.

- **The importance of a unified central leadership:** Li said that a top requirement for the PLA high command is to strengthen armament integration between the air force, ground forces, and navy. This means "raising the level of coordination and combination and preventing the establishment of separate stand-alone systems." Li also hinted at the fierce inter-service rivalry on armaments development and how disruptive it could be to the armament planning process. He said that it was important to "resolutely safeguard the authority and binding force of the plans. Once the armament building plans are approved, no one can change them freely or act in their own way."
- **Prioritizing the building of offensive capabilities:** For much of the PLA's history, the focus has been on developing defensive capabilities to deter against invasion and encroachment of its territorial integrity. This has shifted decisively in the past one to two decades with the country's development and expanding external interests. The priority now, Li pointed out, is to "lay stress on the development of offensive weapons according to the requirement of combining offense and defense."
- **Establishing credible strategic deterrence capabilities:** The PLA should ensure that its strategic deterrence capabilities are operationally tested and deployed so that an "effective and credible deterrence can be guaranteed," Li pointed out. This suggests, for example, that the PLA Navy's ballistic missile submarine fleet will be regularly deployed rather than sit in port.
- **Promoting asymmetric development:** One of the foremost priorities in the PLA's armament building since the late 1990s has been the development of asymmetric capabilities targeted at the vulnerabilities of a stronger opponent, of which the foremost candidate is the United States. Li stressed that "what we should do is to concentrate on developing our unique armaments that can effectively overpower the enemy through systems sabotage against the vital parts and system weaknesses of the opponent." Likely key areas include precision missile capabilities such as anti-ship ballistic missiles, kinetic and non-kinetic anti-satellite assets, and cyber tools.
- **Selective development of advanced armaments:** The principle of selectivity was first put forward by Deng Xiaoping in the 1980s during a period of scarce resource allocations for defense modernization. But with surging funding and strong end-user demand, this guidance appears to have been largely ignored as the PLA and defense industry pursue an ever-lengthening list of weapons projects. Tied with this selectivity requirement is a stress on the pursuit of advanced capabilities, especially by "leaps and bounds." Li points out that, "We should develop key defense technologies and weapons that will play a decisive role in future wars… and spare no effort to achieve successful results in these crucial projects." This priority on high-end innovation at the global technological frontier has benefited the development of capabilities such as stealth aircraft, hypersonic air vehicles, aircraft carriers and carrier-borne combat aircraft, precision missiles, and high-performance computers. But as economic growth slows, there will be pressure on the pace of defense spending and investment, which will force policymakers to choose how to balance quantitative versus qualitative armament development.
- **Striving for indigenous innovation:** Li urged the defense establishment to foster homegrown innovation to limit foreign dependence, but he is aware that there are competing bureaucratic interests on this issue. The defense industry is especially keen to promote technological self-reliance, as they benefit the most from resource allocations. The PLA, and especially the war-fighters, want the best available capabilities as soon as possible, which may mean sourcing from foreign suppliers. Li noted that while self-reliant innovation is critical, "we should grasp

opportunities and actively carry out international cooperation." The prime focus of this foreign engagement would be with Russia.

- **Pursuing civil-military integration:** The armaments apparatus is one of the principal proponents for integration of the civilian and defense economies, and Li points out that the emphasis should be on encouraging civilian entities to participate in research, development, and production along with repair, maintenance, and other support services. Li also says that civil-military integration would help to promote market competition by establishing a competitive procurement process, although there would almost certainly be strong resistance from the country's dominant defense industrial corporations.

Li's instructions offer some interesting insights into the current state of China's armaments strategies and plans. First, a major focus of China's armament development is on how to counter a stronger adversary, primarily the United States, through credible deterrence and asymmetric capabilities. Second, armament development is making solid progress, and the Chinese defense S&T system appears to be making a decisive shift from engaging in absorption and the making of technologically limited products to the development of more innovative and capable capabilities, especially in meeting the PLA's more demanding requirements. Third, despite the progress being made, the structure and processes in which armament development is taking place continues to suffer from deep-seated structural problems such as compartmentalization, weak institutionalization, and heavy reliance on foreign technologies.

Recent Reforms of the PLA Armament System

At the end of 2015, the PLA's armament system underwent a far-reaching reorganization as part of a broader restructuring of the Chinese military establishment. A number of key changes took place.[47]

- The GAD was reorganized into the CMC Armament Development Department (CADD) and has been given responsibility for the centralized unified management (集中统管) of the military armament system.[48] One of the now-defunct GAD's chief roles was to oversee the armament development of the ground forces. The GAD units responsible for this have been transferred to a newly created PLA Land Forces command.
- The GAD Science and Technology Committee was elevated to a commission directly reporting to the CMC and is now known as the CMC Science and Technology Committee (CSTC).

Although it will take some time before these reforms are fully implemented and can be adequately assessed, some initial speculative thoughts can be offered. First, the promotion of the CSTC from the GAD to the CMC demonstrates that the Chinese military authorities, and especially Xi, are increasingly serious about engaging in higher-end STI activities and establishing a high-level coordinating mechanism through the CSTC to provide operational leadership and guidance. Lt-Gen. Liu Guozhi, who was the GAD S&T Committee director, will lead the CSTC. He has spent much

47 "中央军委印发《关于深化国防和军队改革的意见" [Central Military Commission Issues 'Opinions Concerning Deepening the Reform of National Defense and the Armed Forces'], Xinhua, January 1, 2016.

48 "Ministry of National Defense Holds News Conference on CMC Administrative Reform and Reorganization," *China Military Online*, January 11, 2016.

of his career engaged in high-technology R&D. Liu has a PhD in physics from Tsinghua University, is a member of the CAS, and has technical expertise in accelerator physics and high-power microwave technology.[49]

Second, the ability of the new CADD to carry out its mandate of providing centralized management of the armament system looks to have a greater chance of success than the GAD, which was hamstrung by its institutional bias towards the oversight of the ground forces. The nature of the relationship between the CADD and the armament departments belonging to the service arms will be critical in determining how much jointness versus compartmentalization there will in the PLA's armaments development. The authority and influence of the CADD will benefit with the appointment of GAD Director Gen. Zhang Youxia as its new head. Zhang reportedly has close ties with Xi through princeling-related links and has been touted as a contender for a CMC vice-chairmanship.[50]

Special Plans for Defense and Dual-Use Science and Technology Development

China's plans for defense and dual-use S&T development are shrouded in secrecy and not well understood. Besides the MWECP already discussed, there are at least three other important medium and long-term special plans: the MLDP, the 995 High-Technology Development Plan, and the 863 dual-use High-Technology Research and Development Plan.

Medium and Long-Term Defense Science and Technology Development Plan

The MLDP was drawn up in the early 2000s by COSTIND in tandem with the MLP, with the shared goal of overcoming the technological gap with the world's leading technological powers by 2020. The MLDP focuses on guiding defense-related basic and applied R&D and improving the conditions for innovation. An outline of the MLDP highlighted nearly two dozen issues of focus, of which the most important include the following:[51]

- **Enhancing capacity for indigenous innovation and build up the defense innovation system:** This would be carried out by accelerating the reform of the defense R&D system through initiatives such as expanding the number of high-quality defense laboratories engaged in basic research, building technology application centers, establishing closer linkages with leading civilian universities and research institutes, developing a robust service support apparatus to enable activities like technology transfers and commercialization, and allowing defense industrial enterprises to play a more involved role in innovation.
- **Creating a favorable environment to promote innovation:** The authorities recognize the importance of developing a robust governance and norms-based regime that cultivates practices, behavior, and established rules of the road that promote and safeguard innovation. This includes promoting and strengthening incentives for innovation, such as the building up of an

[49] "Former GAD S&T Committee Director Liu Guozhi Appointed Director of New CMC S&T Committee," 澎湃新闻 [*The Paper*], January 11, 2016.

[50] "Former GAD Director Zhang Youxia Becomes New Director of CMC Armament Development Department," 澎湃新闻 [*The Paper*], January 14, 2016.

[51] Commission on Science, Technology, and Industry for National Defense, "国防科技工业中长期科学和技术发展规划纲要" [Outline of Defense Medium- and Long-Term Science and Technology Development Plan], May 29, 2006. See also "China Unveils Plan for Developing Defense Technologies," Xinhua News Agency, May 25, 2006.

IPR protection system, improving planning and coordination to overcome entrenched compartmentalization, constructing a comprehensive defense standards apparatus, forging a rigorous evaluation system, and reforming management procedures and the innovation cultures of R&D organizations that have long been accustomed to a state-dependent 'iron rice bowl' mentality to make them more responsive to market and end user requirements.

- **Increasing the scale and channels of investment in defense science and technology:** State funding for defense R&D has been growing strongly since the late 1990s, but the MLDP seeks to broaden the sources of this investment flow by requiring defense enterprises and research institutes to invest at least 3 percent of their sales revenues in R&D and also allowing them to tap the capital markets for fund-raising through public and private offerings, bonds, and bank loans. The MLDP also promises to establish preferential investment policies, such as tax breaks and generous land use rights.
- **Improving the ability to leverage foreign sources of technology and knowledge transfers:** While the MLDP is avowedly techno-nationalist and emphasizes the overriding importance of self-reliant innovation, it also balances this objective with the need to look overseas to absorb advanced technologies and know-how as well as finding opportunities for international R&D cooperation, including encouraging defense enterprises and research institutes to set up joint research centers and laboratories.
- **Meeting the PLA's requirements for advanced weapons and equipment:** The MLDP points to the importance of adhering to the armament needs of the PLA as set out in the MSG, which includes advancing R&D from the late industrial age to the information era.
- **Promoting civil-military integration:** Finding ways to bring about civil-military integration is strongly encouraged, especially with the goal of making breakthroughs in industrial bottlenecks. A top priority is in advanced manufacturing.
- **Cultivating a capable scientific and engineering workforce:** An Achilles heel of China's defense S&T modernization has been the lack of well-trained and experienced scientists and engineers. The MLDP calls for the establishment of various initiatives to address these manpower shortages, such as through talent training plans, special priority on critical disciplines, and the establishment of defense science, technology, and innovation teams.

The '995' New High-Technology Plan

One of the most important and least known Chinese plans promoting defense S&T development in the twenty-first century is the New High-Technology Plan (高新技术工程). It is more commonly known as the 995 Plan in reference to the US bombing of the Chinese embassy in Belgrade in May 1999 that was the spark for the establishment of this project.[52] The Chinese authorities do not publicly acknowledge the existence of this plan, but it is mentioned in media reports (usually indirectly), military journals, resumes of Chinese scientists and engineers, and project listings of

[52] The Chinese embassy was hit by several precision-guided munitions launched from a US strategic bomber on May 7, 1999, as part of a NATO bombing campaign against the Milosevic regime. The United States said that the attack was accidental and caused by inaccurate targeting data, but there was a strong negative reaction from the Chinese government that disputed the US explanations. 995 refers to the year (99) and month (fifth month, or May) in which the Belgrade bombing took place.

university laboratories and companies engaged in defense-related work.[53] However, in a valedictory message by the GAD upon its reorganization into the CMC Armament Development Department at the end of 2015, it confirmed the existence of the 995 Plan by noting that one of its outstanding contributions in its 17-year history was the "organization and implementation of phases 1, 2, and 3 of the New High-Technology Plan." The reference to the three phases suggests that the 995 Plan was organized in five-year stages to correspond with the five-year weapons and equipment development plans.[54]

The Chinese leadership's reaction to the Chinese embassy attack in Belgrade was to sharply intensify efforts to develop strategic weapons systems, or what the PLA terms *shashoujian* (杀手锏) capabilities.[55] According to Gen. Zhang Wannian, who was the CMC executive vice chairman during the Belgrade Embassy crisis, the CMC convened an emergency meeting immediately following the bombing, and one of the key decisions made was to "accelerate the development of *shashoujian* armaments."[56]

Zhang pointed out that then CMC Chairman Jiang Zemin was especially insistent on the need to step up the pace of development of *shashoujian* megaprojects, saying that "what the enemy is most fearful of, this is what we should be developing."[57] Although the enemy's identity was not made explicit, it was clearly the actions of the United States, and Jiang's guidance to the Chinese defense S&T system was to focus on the R&D of asymmetric capabilities targeting US vulnerabilities.

Jiang also put forward a number of other guiding principles, which most likely formed the outline of the 995 Plan:[58]

- "Do some things but not others, concentrate on developing arms most feared by the enemy": Be selective and focus on asymmetric capabilities.
- "Significantly boost S&T innovation and make breakthroughs as soon as possible": Emphasis on higher-end innovation, which requires a more risk-taking R&D model.
- "Assassin's mace weapons should become the vanguard of the PLA's combat capabilities": This means the development and deployment of advanced high-technology weapons is the PLA's foremost priority.
- "Adhere to self-reliance, but actively introduce and digest advanced foreign weapons and technology": Stepping up efforts to acquire foreign technology transfers by whatever means available, especially by reverse engineering.

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53 See, for example, Sun Hong and Li Lin, "On the Modes of Advancing Weapons and Equipment Development with Chinese Characteristics," *China Military Science*, June 2005; and "Chinese Defense Science and Technology Industry's Tasks for the New High-Technology Program for This and Next Year Are Extremely Heavy," China News Service, April 20, 2004.
54 "For Seventeen Years, We Walked Together."
55 In the defense science and technology domain, *shashoujian* is used by Chinese leaders and analysts to refer to the development of armaments that target an enemy's vulnerabilities. Other less precise, but more colorful, definitions of this term are assassin's mace, trump card, or silver bullet.
56 Zhang Wannian writing team, 张万年传 [*Biography of Zhang Wannian*], 416.
57 Ibid., 419. Possible candidates that fit into the *shashoujian* category include anti-ship ballistic missiles such as the DF-21D, anti-satellite missiles, and stealth aircraft.
58 *Biography of Zhang Wannian*, 416.

One of the most revealing descriptions of the 995 Plan came in a public talk in 2012 by Maj-Gen. Yao Youzhi, a recently retired but influential strategist from the Academy of Military Sciences, the PLA's most important research institute on defense affairs. Yao said that the 995 Plan was established in response to the US bombing of China's Belgrade embassy and its purpose was to accelerate research and development of new weapons systems.[59] "Without 995, the PLA would not have been able to get new generations of weapons developed as quickly as was achieved," Yao said, and referred to the 2009 National Day military parade in which 40 types of new weapons were displayed as evidence of the impact. "Who should we be ultimately thankful for" in enabling the PLA to make such progress, Yao asked rhetorically. "We should be grateful to the Americans." This remark suggests that the 995 Plan was primarily aimed at the United States.

To ensure that these major weapons projects receive high-level attention, the CMC established a New High-Technology and Engineering Leadership Small Group (中央军委新高科技工程领导小组-995 LSG) in 1999 with the CMC chairman as its head. This coordinating body is responsible for providing top-level unified leadership and management of the development of high-technology weapons systems.[60] This leading group appears to have similar characteristics and roles as the Central Special Committee (中央特别委员会), which was established in the early 1960s to manage the development of the country's nuclear weapons and strategic launch capabilities and continues to function to the present day.[61] The activities of the 995 LSG are rarely disclosed, but a defense industry newspaper reported in December 2014 that there was a 995 LSG attended by Xi Jinping that took place in conjunction with an All-Army Armament Conference (全军装备工作会议).[62]

The '863' High-Technology Research and Development Plan

In the mid-1980s, a group of four senior scientists and engineers who were closely involved in the country's strategic weapons projects of the 1950s and 1960s petitioned China's paramount leader Deng Xiaoping to support the development of S&T development in strategic areas that were deemed crucial to the country's national security and economic competitiveness. In the post-1978 reform era, funding for national security-related topics had been drastically cut and the scientists were worried that the country's strategic R&D capabilities were in danger of being lost. Deng approved the proposal, which led to the creation of the "High-Technology Research and Development Plan," although it is better known as the '863' Plan to commemorate the date of its establishment in March 1986.

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[59] Talk by Yao Youzhi at the Shenzhen Culture Forum, August 18, 2012, http://www.szccf.com.cn/wqhg_content_662.html.

[60] Zhou Bisong, 中国特色武器装备建设道路研究 [*Research on the Path for the Construction of Weapons with Chinese Characteristics*] (Beijing: National Defense University Press, 2012), 39.

[61] Tai Ming Cheung, "The Special One: The Central Special Committee and the Structure, Process, and Leadership of the Chinese Defense and Strategic Dual-Use Science, Technology, and Industrial Triangle," paper presented at Conference on the Structure, Process, and Leadership of the Chinese Science and Technology System, University of California, San Diego, July 2012.

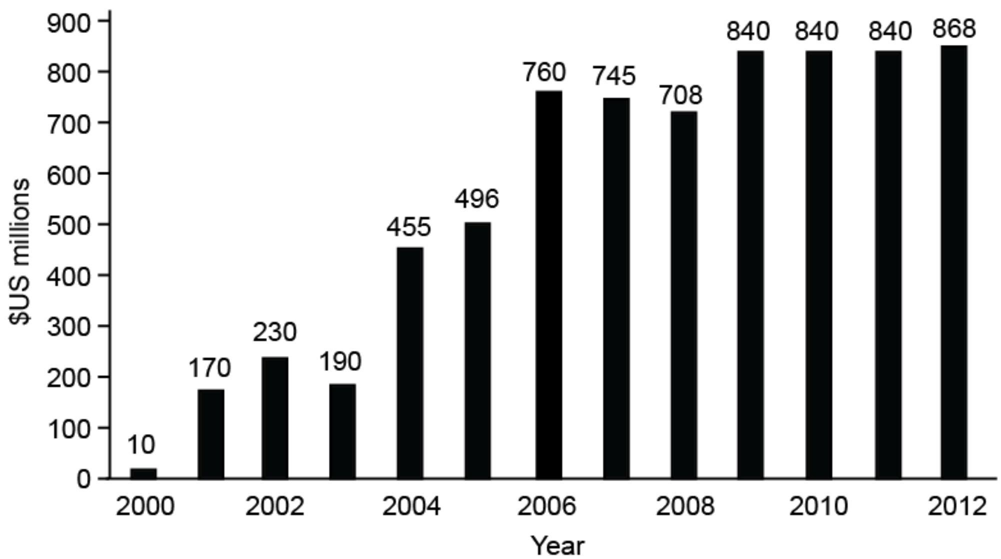
[62] "AVIC Studies and Implements Spirit of All Army Armaments Work Conference," 中国航空新闻网 [*China Aviation News*], December 15, 2014.

The 863 Plan initially highlighted seven areas deemed central to China's future national security and economic prowess: automation, biotechnology, energy, information technology, lasers, new materials, and space technology. Several more sectors were added subsequently, including environmental technology, marine technology, and earth observation and navigation technology. The plan was directly modeled on the organizational structure and operational procedures of the Maoist strategic weapons plan.[63]

The 863 Plan has grown significantly in size, scope, and importance, especially since the beginning of the twenty-first century when funding sharply increased in scale (Figure 4). Through the establishment of expert leading groups and specialized research centers, this plan helped to introduce, nurture, and diffuse cutting-edge technological products and processes in leading economic sectors. In the information technology industry, for example, projects have focused on the development of high-performance computing, optical electronics, telecommunications, and artificial intelligence.

The 863 Plan was intended to straddle the civil-military divide. One study suggests that there was a programmatic goal in which 39 percent of projects would be for civilian use, 45 percent would be of a dual-use nature, and the remaining 16 percent would be for national security applications.[64]

Figure 4. Annual 863 budget expenditures, 2000–2012 (civilian projects only)



Source: Ministry of Science and Technology, 863 and Science and Technology Plan annual reports 2001 to 2013.

[63] Evan Feigenbaum, *China's Techno-Warriors: National Security and Strategic Competition from the Nuclear to the Information Age* (Palo Alto, CA: Stanford University Press, 2003).

[64] Han Hua, "军口 863 项目固定资产采购决策与动态评估研究" [Study of the Procurement Decision-Making and Fixed Asset Assessment of Projects Belonging to the Military 863 Program] (PhD dissertation, Huazhong Science and Technology University, 2007), 2.

Defense scientists and engineers have played active roles in many projects to ensure that defense requirements are taken into consideration and to identify and gain access to any technologies that may be useful for military application. The 863 Plans that are of most value for military application include the space, laser, optoelectronics, very large scale integrated circuits, turbofan engines, and new materials plans.[65] The GAD is directly in charge of the 863 space and laser project domains. According to official accounts, nearly 10,000 defense scientists and engineers have been involved in the 863 Plan, working on more than 1,500 research projects and making more than 100 important technological breakthroughs by the early 2000s in areas such as space technology, computers and information technology.[66] The Shenzhou manned space plan was one of the leading achievements of the 863 plan.

One complaint leveled against the 863 Plan during the 1990s was that it was too preoccupied with basic and esoteric R&D projects, with little effort devoted to applying its output for the country's development. This led to a major strategic readjustment of the plan at the beginning of the twenty-first century. This also reflected the efforts of the government to promote commercialization throughout the S&T community. Other government plans that have also contributed to the development of dual-use civil-military technologies include the Torch plan, which is intended to commercialize high-tech R&D inventions, and the 973 Plan.

Although the 863 Plan enjoys strong political support and generates high-quality research results, the central authorities announced in 2015 that the plan would be included in a far-reaching overhaul of the S&T funding process that is aimed at consolidating around 100 plans managed by forty government agencies. The new management structure will have five categories of plans, of which most, if not all, of the projects belonging to the 863 Plan will fall under the portfolio of the National Key Research and Development Plan (国家重点研发计划). Other categories that might take responsibility for 863-related activities include the National Major Science and Technology Plan (国家科技重大专项) and National Natural Science Fund (国家自然科学基金). Government agencies will no longer be responsible for the operational management of these plans, which will be carried out by professional S&T management organizations.

This reform will not be completed until 2017, so the exact nature of the post-863 successor plan has yet to be finalized. The actual impact will depend on successful implementation of reforms. This revamping of the S&T funding system will primarily affect the civilian portion of the 863 Plan; there is little information as to how the military 863 component will be affected.

B. CIVILIAN SCIENCE, TECHNOLOGY, AND INDUSTRIAL DEVELOPMENT PLANS

China's Science and Technology Plans: Background and Progress

While the state has gradually retreated from direct management of the Chinese economy in the post-Mao reform era, the S&T sector stands out as being subject to more state planning than ever in its history. Besides the regular five-year plans, the Chinese authorities have enacted a raft of blueprints that provide a top-down hands-on guidance on the means and ends for China to catch up with the rest of the world. They range from comprehensive formulations such as the MLP to

[65] "Very large scale integrated circuits" refers to the combination of thousands of transistors into a single chip.
[66] Liu Cheng, "Creating a New Situation in the Weapons and Equipment Modernization Effort."

more specialized documents targeting particular areas such as strategic emerging industries and advanced manufacturing (Figure 5).

This section reviews five key state plans: 1) the MLP; 2) the SEI; 3) the 973 Plan; 4) the five-year planning process, especially the 12th and 13th FYPs; and 5) the Made in China 2025 plan and related Internet Plus plan, introduced in May and July 2015 respectively. In addition, there will be a review of the CAS's "Roadmap to 2050" and an examination of recent efforts by the central authorities to consolidate the proliferation of scores of overlapping plans that have been established over the past few decades.

National Medium- and Long-Term Plan for Science and Technology Development (2006–2020)

When President Hu Jintao and Premier Wen Jiabao assumed power in the early 2000s, they began to examine the formulation of a large-scale initiative to improve the country's S&T capabilities, especially in critical strategic areas. Under Wen's direction, planning began in 2003 on what became known as the MLP.[67] The MLP was conceived by a leadership that saw the first 20 years of the twenty-first century as a strategic opportunity to catch up with the world's leading advanced economic and technological powers. The drafting of the plan took three years, and thousands of scientists, engineers, academics, economists and military experts examined 20 issue areas deemed vital to China's S&T competitiveness. They included agricultural S&T, basic science, S&T popularization, energy and resource S&T, national security, the national innovation system, and manufacturing.[68]

The nature of the MLP preparatory process was a throwback to the height of Cold War central planning in the late 1950s when China embarked on its first long-term S&T development plan. The 12-year national S&T plan launched in 1956 had 12 key tasks (not unlike the megaprojects contained in the MLP) that were intended to support the building of key strategic sectors such as nuclear energy, missiles, computers, and automation technology.[69] This plan was implemented until the early 1960s, but no new detailed long-term plans were drawn up until the 2006–2020 MLP. Other mostly failed attempts at long-range S&T planning initiatives included: 1) a ten-year plan issued in 1963 that replaced the earlier 12-year S&T blueprint but which was aborted during the Cultural Revolution; 2) a medium-term development plan for 1978–1985; and 3) a 1990–2000 S&T development outline.[70] There was also a proliferation of other shorter planning efforts and development plans such as the regular five-year plans and the 863 and 973 plans.

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[67] State Council, "Guidelines for the Implementation of the National Medium- and Long-Term Plan for Science and Technology Development (2006–2020)," February 2006.

[68] Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan"; Hao Xin and Gong Yidong, "China Bets Big on Big Science," *Science,* March 16, 2006, 1548–49.

[69] Xie Guang, chief ed., *Dangdai Guofang Keji Shiye* [*The Contemporary Chinese Defense Science and Technology Sector*] (Beijing: Contemporary China Press, 1992), 32.

[70] Liu Li, *Research Priorities and Priority-Setting in China* (Stockholm: Vinnova, 2009), 15.

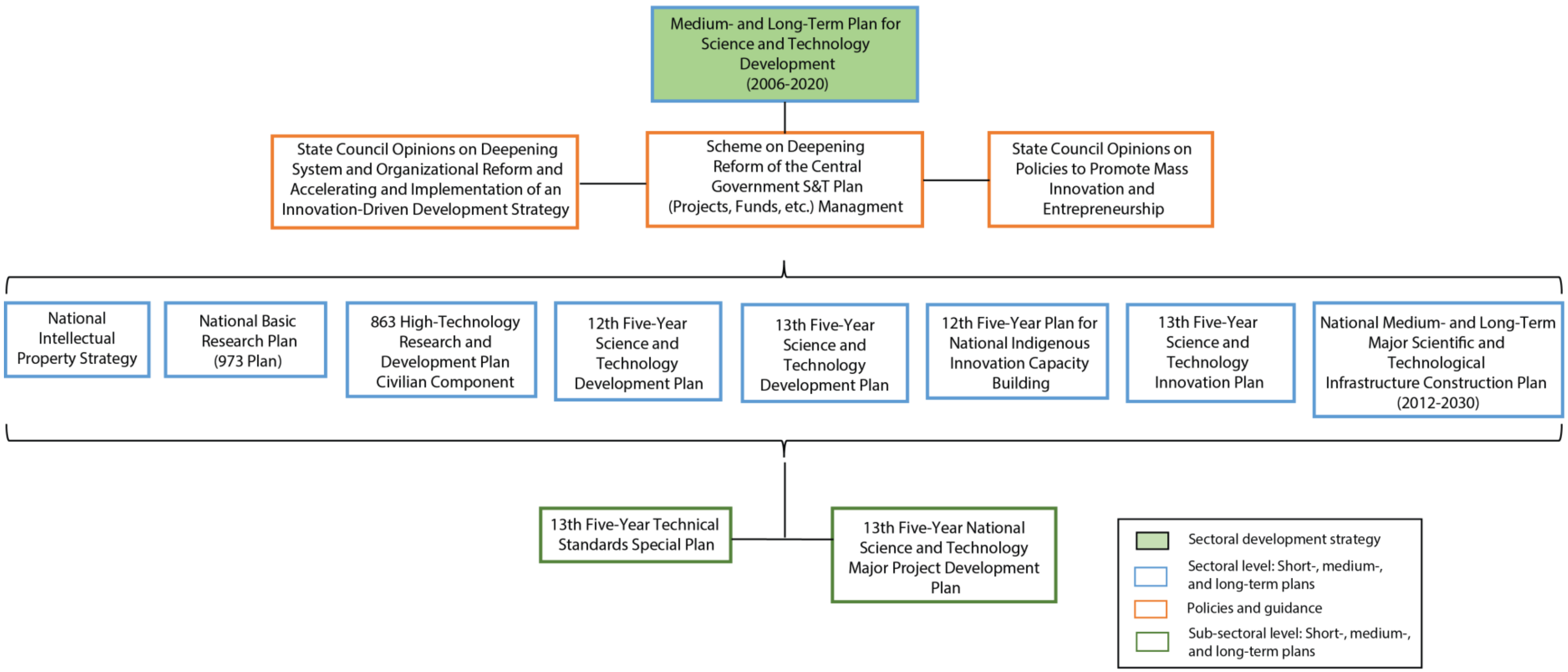

Figure 5. China’s state strategies and plans for science and technology development

Major debates took place during the drafting of the MLP over the fundamental orientation of the plan.[71] One debate revolved around the relationship between indigenous innovation and technology imports. Leading economists argued that China should retain its existing technological development model of attracting foreign multinationals and encouraging technology transfers to boost the country's S&T competence. Many scientists opposed this view and insisted that China could not depend on getting core technology from other countries. The scientific community eventually prevailed and the MLP reflects the changed focus in the Chinese S&T development model towards indigenous development.

A second polarizing issue was whether the focus should be on the implementation of megaprojects in which the state played a central organizing role, or the emphasis should be on a more decentralized, bottom-up, market-driven process. Those who advocated the adoption of the "small science" (小科学) approach said that pursuit of large-scale projects diverted resources from more original and innovative investigator-driven projects. Some of these scientists, especially US-based Chinese scholars, were critical of plans like the 863 that they said were biased, inefficient, non-transparent, and awarded based on insider connections.[72] But those in favor of the "Two Bombs, One Satellite" (两弹一星)-inspired "Big Science" (大科学) model could count on high-level political support, and they eventually won out in this debate.[73]

The MLP was promulgated in 2006 and has a strong techno-nationalist tone. In viewing the fundamental relationship between national security and technological development, the MLP defines this linkage in stridently realist terms: "Facts tell us that we cannot buy true core technologies in key fields that affect the lifeblood of the national economy and national security." To address this vulnerability, one of the central concepts put forward in the MLP is the notion of indigenous or independent innovation (*zizhu chuangxin,* 自主创新*),* which seeks to promote the country's S&T capabilities through improving the absorption and "re-innovation (再创新)" of foreign technology as well as investing in the building of a national innovation system to nurture development of original, homegrown innovation.

Another fundamental principle of the MLP is the centrality of national security in the development of a world-class independent S&T capability. Consequently, defense and civil-military dual-use priorities are of utmost importance. In the published version of the MLP, however, there are few details of defense-related S&T projects. They are instead contained in the MLDP. The MLP seeks to blur the classical distinction between civilian and military technologies and points out that S&T development should benefit both civilian and defense needs at the same time.

[71] See Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan," for a discussion of the debates.
[72] Cao, Suttmeier, and Simon, "China's 15-Year Science and Technology Plan"; Hao Xin and Gong Yidong, "China Bets Big on Big Science."
[73] The "Two Bombs, One Satellite" model refers to the success of the Chinese defense research and development system in the development of nuclear weapons and space capabilities between the late 1950s and early 1970s.

One of the MLP's signature initiatives is the development of 16 major special projects that are considered important for enhancing national competitiveness (Table 1). Thirteen of these so-called megaprojects were identified in the MLP, but another three were unnamed because they were classified defense projects. A sizeable number of the open projects could have both civilian and defense applications, which was one of the guiding principles in the selection of many of these plans. They included high-grade, computer numerically controlled (CNC) machine tools, core electronic components and high-end universal chips, high-resolution Earth observation systems, nuclear power stations with large-scale advanced pressurized water reactors and high-temperature and gas-cooled reactors, large passenger aircraft, and the Shenzhou manned space flight and Chang'e lunar exploration projects.

The performance of these megaprojects have been decidedly mixed. Several of the key strategic plans with both civil and military potential applications have made significant progress in their development, of which the manned space flight and lunar exploration projects stand out. This can be attributed in large part to the extensive high-level leadership support and substantial funding they have received. Not surprisingly, projects that are less related to strategic and security concerns, such as those in the environmental pollution and healthcare areas, have lagged in their development.

Table 1. List of announced MLP megaprojects

Project Name	Administration
Core electronics, high-end general chips, basic software	Ministry of Industry and Information Technology (MIIT)
ULSI manufacturing technology and complete sets of technology	Beijing, Shanghai municipal governments
Next generation broadband wireless mobile communication	MIIT, Datang Electronics, Chinese Academy of Sciences (CAS), Shanghai Institute of Microsystems, China Putian Corporation
High-end CNC machine tools and basic manufacturing technology	National Development and Reform Commission, MIIT
Large-layer oil and gas fields and coal-bed methane development	China Petroleum, China United Coal-bed Methane Company
Large-scale advanced pressurized water reactor nuclear power	Ministry of Science and Technology (MOST), National Energy Bureau, Tsinghua University
Water pollution control and treatment	Ministry of Environmental Protection
Genetic transformation breeding of new plants	Ministry of Agriculture
Create major new drugs	MOST, Ministry of Health, PLA General Logistics Department
Prevention and control of major infectious diseases	MOST, Ministry of Health, PLA General Logistics Department
High-resolution Earth observation system[74]	China National Space Administration, State Administration for Science, Technology, and Industry for National Defense (SASTIND)
Large passenger aircraft	MIIT, Commercial Aircraft Corp. of China
Manned space flight and lunar exploration project	PLA General Armament Department, SASTIND, CAS, China Space Technology Industry Corporation

[74] High-resolution earth observation systems are capable of taking imagery at a resolution of of 1−2 meters, which allows them to distinguish man-made objects. This makes them useful for both military (reconnaissance and targeting) and civilian purposes.

Overall, the Chinese authorities appear to have been a little disappointed with the MLP's progress. A review of the state of the country's STI development at a July 2012 conference led by Hu and Wen was highly critical of the poor returns on the enormous amount of investment that had been poured into the S&T system since the commencement of the MLP. Between 2006 and 2012, RMB 4.3 trillion ($668.6 billion) had been invested in R&D, of which around half came from central government appropriations.[75] The conference noted that there was chronic waste and disorderly implementation of development plans because of extensive duplication of activities and a deeply fragmented bureaucratic apparatus, a focus on imitative rather than truly innovative projects, and a lack of progress in developing core technologies.[76] Many of these criticisms were echoed by Wen in a leading Communist Party-affiliated journal, in which he judged that the "Chinese capacity for indigenous innovation is weak, Chinese industrial technology is at a low level, and Chinese basic and cutting-edge research is unimpressive."[77]

A number of steps were taken following the conference to address the shortcomings of the STI system and undertake a course correction of the MLP. A policy document issued in September 2012 entitled "Opinions on Deepening Reform of the Science and Technology Management Structure and Speeding Up Construction of the National Innovation System" put forward a number of initiatives. Key reforms that were highlighted included: 1) emphasizing the pivotal role of enterprises in innovation; 2) improving collaborative innovation between enterprises, universities, and research institutes; 3) revamping the S&T management system by addressing compartmentalization and improving performance evaluations; and 4) bolstering the governance regime such as by strengthening IPR. This was followed in February 2013 with the unveiling of a 'National Innovation Capability Building Plan' that was intended to make the national innovation system more rational and integrated through efforts such as revamping national engineering centers, optimizing the distribution of regional innovation capabilities around the country, and increasing R&D outlays for enterprises.[78]

While the MLP will continue to be an important roadmap to guide China's S&T development to the end of this decade, the interest and support for the plan in the Xi Jinping era is far less enthusiastic. Its chief supporter and architect Wen Jiabao retired in 2013, which deprives the MLP of a high-level advocate, and Xi has turned his focus to new initiatives such as the innovation-driven development concept and the Made in China 2025 and Internet Plus plans.

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[75] For purposes of comparison, a conversion to dollars has been provided for all foreign currency amounts, using the annual rate for the period December 17, 2014–December 17, 2015 from OANDA Corporation (http://www.oanda.com/currency/historical-rates/). For euros to dollars, the rate used was 1.0936; for RMB to dollars, the rate used was .1555. The dollar equivalents may vary slightly from those given in sources cited in the report.
[76] "Chinese Top Leaders Call for Innovation in Science, Technology," Xinhua, July 7, 2012, http://news.xinhuanet.com/english/china/2012-07/07/c_131701407.htm.
[77] Wen Jiabao, "关于科技工作的几个问题" [Several Problems Regarding the Science and Technology Work], 中央政府网站 [www.gov.cn], July 16, 2011, http://www.gov.cn/ldhd/2011-07/16/content_1907593.htm.
[78] "China's First Plan for Building Independent Innovation Capability Published," *Science and Technology Daily*, February 21, 2013.

The Strategic Emerging Industries Initiative

Only a couple of years after the adoption of the MLP, the Chinese authorities began to draft a new S&T development plan that was aimed at supporting innovation in what they viewed as areas of vital strategic economic importance to the country's long-term global competitiveness. This was dubbed the Strategic Emerging Industries initiative (*Zhanluexing Xinxing Chanye* 战略性新兴产业) and was in response to the onset of the 2008 global financial crisis that threatened to seriously dent China's economic growth.[79]

The SEI initiative offers an important broadening of the boundaries of what constitutes the strategic innovation system, from its traditional national security-oriented, techno-nationalist orientation to cover a more diverse and economically directed techno-globalist set of actors (especially provincial authorities and enterprises), and new development priorities. Central government agencies involved in the management of the SEI plan include the National Development and Reform Commission (NDRC), the Ministry of Commerce (MOFCOM), MOST, MIIT, the Ministry of Finance (MOF), and the State Intellectual Property Office. The NDRC is in charge of a special ad hoc inter-ministerial coordination group to formulate SEI plans and policies.

Seven newly industrializing sectors were selected to become the backbone of China's next phase of industrial modernization and technological development (Table 2). Four of these areas were already included in the MLP, such as high-end equipment manufacturing, next-generation information technology, biotechnology, and advanced materials. Alternative energy, energy efficient and environmental technologies, and new-energy vehicles were added for the first time.

Each of these seven sectors has numerous subsectors identified for priority development, so the actual footprint of the SEI plan is extensive. The high-end equipment manufacturing sector, for example, covers the development of the aviation, railway, space, marine engineering, and intelligent manufacturing equipment sectors. Of the seven industries, only the high-end equipment manufacturing and advanced materials would also directly benefit the defense sector.

The State Council released a policy document in October 2010 that set out the scope and goals of the SEI initiative. "The Decision on Accelerating the Development of Strategic Emerging Industries (国务院关于加快培育和发展战略性新兴产业的决定)" put forward a highly ambitious target of the SEIs to produce eight percent of GDP by 2015 and 15 percent by 2020.[80] It was not until 2012, however, that the central authorities began to issue concrete policies and measures to implement the plan. The principal document was the 2011–2015 12th Five-Year Plan on Development of Strategic Emerging Industries, which laid down specific goals, sub-industry priorities, key projects, and supportive policies.[81] This was followed by several catalogues put out by the MIIT and

[79] US–China Business Council, "China's Strategic Emerging Industries."
[80] State Council, "Decision on Accelerating the Development of Strategic Emerging Industries," October 2010, www.gov.cn/zwgk/2010-10/18/content_1724848.htm.
[81] State Council, "12th Five-Year Plan on Development of Strategic Emerging Industries," July 2012, www.gov.cn/zwgk/2012-07/20/content_2187770.htm.

NDRC that provided classification of specific industries entitled for SEI policy implementation and for detailed lists of technologies and products.[82]

Table 2. The seven sectors of the SEI initiative

SEI	Focus	Goal	Lead ministry(ies)
Energy-saving environmental industry	High efficiency and energy saving, advanced environmental protection, key technology, equipment, products, and services for resource recycling, clean coal, seawater comprehensive utilization	By 2015, industrial added value reaches RMB 4.5 trillion ($699.75 billion) (2 percent of GDP)	NDRC, MEP, MIIT, MWR
New information technology industry	New mobile communication, next-generation Internet, tri-networks integration, cloud computing integrated circuits, new displays, high-end software, high-end servers, information services, digital virtual technology	Accelerate the construction of the next-generation information network; breakthrough in new generation IT technologies	MIIT
Biology industry	Biomedical, biomedical engineering products, bio agriculture, bio manufacturing, marine biotechnology	Attain economic growth and be competitive in global markets by 2015	NDRC
High-end equipment manufacturing industry	Aviation equipment, satellites and their applications, railway vehicles, marine engineering equipment, intelligent manufacturing equipment	Achieve RMB 6 trillion ($933 billion) in sales in 2015, making up 15 percent of total equipment manufacturing industry; a pillar for the national economy	MIIT
New energy industry	New generation nuclear power, solar energy thermal applications, solar thermal and solar PV electricity, wind energy technology equipment, smart grid, biomass energy	By 2015, proportion of new energy consumption should reach 12−13 percent	NDRC, MIIT
New material industry	New functional materials, advanced structural materials, high-performance fiber and composites (carbon fiber, aramid fiber, ultra-high molecular weight polyethylene fiber), and common basic materials	By 2015, total industrial value should reach RMB 2 trillion ($311 billion) with annual rate increase of 25 percent; popularize 30 new materials	MIIT
New-energy automobile industry	Key technologies for power cells, drive motors, electronic controls, plug-in hybrid electric vehicle, battery electric vehicle, and fuel cell electric vehicle technology	Cultivation and development of new energy automotive industry; advance R&D efforts and global cooperation	MIIT

[82] Ministry of Industry and Information Technology, “Classification Catalogue of Strategic Emerging Industries,” November 2012, www.miit.gov.cn/n11293472/n11293832/n12845605/n13916913/14990105.html; National Development and Reform Commission, “Guiding Catalogue for Strategic Emerging Industries’ Key Products and Services,” February 2013, www.ndrc.gov.cn/zcfb/zcfbgg/2013gg/t20130307_531611.htm.

The SEI initiative represents a spin-off from the mainstream techno-nationalist framework to the incorporation of a more cooperative ‘techno-globalist’ oriented approach. One of the new guiding principles is an emphasis on expanding international cooperation in all seven sectors to “make better use of global S&T achievements” and allow Chinese firms to compete more effectively in external markets.[83] Another difference from the MLP is that the SEI is aimed primarily at developing technological capabilities for social and economic goals, such as tackling environmental pollution and nurturing sustainable energy resources, while there is limited attention paid to national security considerations.

The ‘973’ National Basic Research Plan

The National Plan on Key Basic Research, more commonly known as the 973 Plan, was established in 1997 under the management of MOST with the central goal of strengthening support for early-stage basic research on major scientific issues related to economic and social development.[84] Many of the key areas of scientific investigation designated by the 973 Plan are based on research projects supported by the National Natural Science Foundation of China.

The plan originally supported seven areas that included agriculture, energy, information technology, resources and environment, health sciences, materials science, and research at the major scientific frontiers. Integrated multidisciplinary sciences were added as a focus area in 2003. An additional four areas were added in 2006: nanotechnology, quantum control research, protein, and development and reproduction.[85]

A key priority for the 973 Plan is cross-disciplinary research with the purpose of generating new areas of scientific knowledge. The plan also seeks to support research teams led by junior and mid-level scientists to nurture the next generations of scientific leadership.

From 1998 to 2004, the overall budget for the 973 Plan was RMB 4.2 billion ($653.1 million). This nearly tripled to RMB 11.5 billion ($1.79 billion) during the 11th FYP.[86] In an effort to reform its S&T management system, however, MOST announced in January 2015 that the 973 Plan would be merged with other major S&T plans by 2017. The aims of this reform are to further improve innovation and to promote more efficient use of research funds by delegating power to independent institutes in order to limit corruption in academic circles.[87]

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[83] “Hu Jintao at 29th Politburo Collective Study Session Emphasizes Need to Firmly Seize Historic Opportunities and Earnestly Step Up Efforts to Promote Rapid and Sound Development of Strategic Emerging Industries,” Xinhua Domestic Service, May 31, 2011.

[84] Ministry of Science and Technology, “National Basic Research Program of China (973 Program)” website, accessed October 14, 2015, http://www.most.gov.cn/eng/programmes1/200610/t20061009_36223.htm.

[85] “国家重点基础研究发展计划 (973 计划) 大事记” [Chronicle of Events: National Program on Key Basic Research Project (973 Program)], 中国基础科学 [China Basic Science] (2008/5): 61–63.

[86] European Commission, Erawatch, “National Basic Research Development Programme (973 Programme)” accessed October 14, 2015, http://erawatch.jrc.ec.europa.eu/erawatch/opencms/information/country_pages/cn/supportmeasure/support_mig_0004.

[87] Yi Junying, “中国科研经费分配新办法出炉 ‘863’等将被取消” [Issuance of New Plan for Management of Scientific Research Funding in China: 863 and Other Programs Will Be Eliminated], Xinhua News, January 8, 2015, http://www.qh.xinhuanet.com/2015-01/08/c_1113917119.htm.

The Five-Year Plans and Xi Jinping's Innovation-Driven Development Strategy

Since China first adopted the Five-Year Plan model of economic management in 1953, it has become, as Scott Kennedy points out, "the most authoritative statement of the leadership's economic priorities and identifies broad policies on how to achieve them."[88] Like the Chinese economy, the FYP has undergone considerable evolution since its establishment. From a mandatory planning instrument during the central planning era, the FYP turned into a tool for coordination, guidance, consensus building, and evaluation since the early 1990s and today is a "continuous cycle of policymaking."[89]

In the post-1978 reform and open door era, the FYPs have played an important but declining role in contributing to the strong growth of the Chinese economy, which averaged 9.8 percent between the 6th and 12th FYPs (Table 3).[90] The 12th FYP almost certainly represents the end of the high-growth era of Chinese economic development, which is reflected in the trajectory of declining growth rates over the course of the plan. GDP growth in 2011 was an impressive 9.3 percent, despite the continuing effects of the global financial crisis. Growth in 2012 and 2013 slowed to an annual average of 7.7 percent, and further declined to 7 percent in 2014 and 6.9 percent in 2015. The annual average growth of the 12th FYP was 7.8 percent, which was nearly one percent higher than in the plan's original outline.[91]

S&T priorities assumed growing importance during the progress of the 12th FYP. The pace and scale of R&D funding enjoyed robust growth and reached above 2 percent as a percentage of GDP for the first time ever in 2013. This deepening investment was rewarded with a number of major S&T accomplishments. The space sector was one of the stand-outs with the Shenzhou and Tiangong manned space flight plans, the Chang-e lunar exploration project, Gaofen-2 earth remote sensing satellite, Kuaizhou solid rocket launch vehicle, and the Beidou satellite navigation plan. Other notable achievements included the development of Jiaolong unmanned underwater vehicle, Tianhe-2 supercomputer, high-temperature superconductors, and important advances in stem cell research. Minister of Science and Technology Wan Gang also pointed out progress in transportation technologies, such as the increase in the speed of China's high speed rail locomotives from 250 to 380 km/hour and an increase in the number of alternative energy vehicles operating in China to 120,000. Progress has also been made in information technologies, including advancements in the Internet industry, e-commerce, domestic CPUs, and operating systems, and China has established the world's largest 4G telecommunications network with 70 million users.[92] While these

[88] Scott Kennedy, "Impressions of the 13th FYP Proposal," in *State and Market in Contemporary China: Toward the 13th Five-Year Plan,* ed. Scott Kennedy (Lanham, MD: Center for Strategic and International Studies and Rowman & Littlefield, 2016), 48–49.
[89] Oliver Melton, "China's Five-Year Planning System: Structure and Significance of the 13th FYP," in Kennedy, *State and Market in Contemporary China*, 42–43.
[90] For a good overview, see Barry Naughton, *Growing Out of the Plan: Chinese Economic Reform, 1978–1993* (Cambridge: Cambridge University Press, 1996).
[91] "国务院关于《中华人民共和国国民经济和社会发展第十二个五年规划纲要》实施中期评估报告" [Mid-term Evaluation Report of the State Council on the Implementation of the Outline of the Twelfth Five-Year Plan for National Economic and Social Development of the People's Republic of China], National People's Congress, National Development and Reform Commission website, April 9, 2014, http://www.npc.gov.cn/npc/xinwen/2013-12/26/content_1820964.htm.
[92] "MOST Minister Wan Gang Discusses S&T Reform and Development."

results are encouraging, in overall terms they represent a meager return for the enormous amount of resource allocations that have been expended on S&T. Total state expenditures on S&T during the 12th FYP was around RMB 3 trillion ($466 billion).[93]

In the search for a new development model, the Chinese authorities have sought to embrace the market to spur sustainable long-term growth and pave the way for a more market-oriented and bottom-up approach to innovation. This was underlined at the Third Plenum of the 18th Party Central Committee in November 2013 with the issuance of the "Decision on Major Issues Concerning Comprehensively Deepening Reform." This decision is an ambitious statement of intent by Xi to undertake major reforms on numerous fronts, including in the economic, STI, social, and defense domains. One of the central points highlighted in the plenum document was that reforms should allow the "market to play a decisive role in allocating resources."[94]

Table 3. Annual average GDP growth in China between the 6th and 12th Five-Year Plans

Five Year Plan	GDP growth (average annual %)
6th (1981–1985)	10.8
7th (1986–1990)	8.0
8th (1991–1995)	12.3
9th (1996–2000)	8.6
10th (2001–2005)	9.8
11th (2006–2010)	11.3
12th (2011–2015)	7.8
13th (2016–2020)	6.5 (13th FYP)
	6.6 (World Bank)
	5.54 (EIU)
	6.2 (IMF)
	6.4 (Rhodium Group)

Notes: For historical GDP data, see the World Bank, "GDP Growth (Annual %)," accessed February 19, 2016, http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG. The World Bank 2016–2020 forecast is an average of estimates provided for the years 2016 and 2020. All other forecasts are averages of estimates provided for 2016–2020. The Rhodium Group forecast is its forecast for a soft landing. For World Bank, EIU, and IMF forecasts, see Knoema, "China GDP Growth Forecast 2015–2020 and Up to 2060, Data and Charts," accessed February 19, 2016, http://knoema.com/loqqwx/china-gdp-growth-forecast-2015-2020-and-up-to-2060-data-and-charts. For the Rhodium Group forecast, see Daniel H. Rosen and Anna Snyder, "China's Outlook: Now and in 2020," Rhodium Group, August 8, 2014, http://rhg.com/notes/chinas-outlook-now-and-in-2020.

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[93] State expenditures on S&T for 2011–2013 come from National Bureau of Statistics and Ministry of Science and Technology, *2014 China Statistical Yearbook on Science and Technology* (Beijing: China Statistics Press, 2014), 15. The figure for 2014 comes from the "2014 Statistical Bulletin of National S&T Investment," Xinhua, November 23, 2015. The 2015 figure is an estimate based on the same ratio of S&T expenditure as a percentage of total government expenditures as in the previous year.
[94] "CPC Acknowledges Market's "Decisive" Role," Xinhua, November 12, 2013, http://news.xinhuanet.com/english/china/2013-11/12/c_132882359.htm.

In the STI arena, the Chinese leadership has come up with the concept of "innovation-driven development (国家创新驱动发展)," which represents a significant shift from the state-led top-down approach that has been the dominant model of STI development over the past few decades.[95]

While "innovation-driven development" was first mentioned as a major new initiative at the 18th Party Congress in 2012, it was not until 2014 that it began to be fleshed out by Chinese leaders. At a meeting of the Financial and Economic Affairs Leading Group (FEALG) in August 2014, Xi ordered the NDRC and FEALG to take the lead to formulate detailed guidance for implementation of the innovation-driven development strategy. This resulted in the issuance of the "Opinions on Accelerating Implementation of the Innovation-Driven Development Strategy through Strengthening Institutional Reforms" by the State Council in March 2015.[96]

It is noteworthy that the drafting process was led by the NDRC and FEALG because these two entities are heavyweight players in economic policymaking and have significantly more bureaucratic clout and political influence than ministerial-level organs such as MOST. One important caveat is that the NDRC is a leading bastion of conservative state planning in Chinese economic policymaking and implementation, and has reportedly clashed with more reform-minded leaders about its willingness to carry out reform initiatives, such as over urbanization policy.[97] There have been some efforts in the past few years to tackle the NDRC's deep-rooted anti-reform skepticism, such as appointing pro-reform outsiders like current NDRC director Xu Shaoshi and deputy director Liu He to its leadership and rolling back its approval authority for major projects.[98]

The Opinions contain a number of major reform targets:

1. **Identify and remove institutional barriers to innovation.** Key areas of focus include overhauling the IP protection system and removing industrial monopolies, which the central authorities have long advocated but have been stymied by powerful vested interests.
2. **Improve the incentive structure for innovation outcomes for researchers** so that they are better rewarded for their work, such as the ability to earn payment and equity rights to their innovations.

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95 "李乃胜：关于深化科技体制改革的几点思考" [Li Naisheng: Several Considerations on Deepening S&T System Reform] 中国教育和科研计算机网 [China Education and Research Network], September 14, 2015, http://www.edu.cn/zhuan_jia_ping_shu_1113/20131204/t20131204_1047871.shtml. Xi quoted in "科技部关于开展"十三五"国家重点研发计划优先启动重点研发任务建议征集工作的通知" [Notice on MOST Beginning 13th FYP National Key R&D Plan to Prioritize Key R&D Tasks by Soliciting Suggestions], February 13, 2015, http://www.most.gov.cn/mostinfo/xinxifenlei/fgzc/gfxwj/gfxwj2015/201502/t20150216_118249.htm.

96 "中共中央 国务院关于深化体制机制改革加快实施创新驱动发展战略的若干意见" [CPC Central Committee and State Council Opinion Regarding Deepening the Reform of Institutional Mechanisms, Accelerating Implementation of Innovation-driven Development Strategy], 新华社 [Xinhua News], March 13, 2015, http://www.gov.cn/xinwen/2015-03/23/content_2837629.htm.

97 For background on NDRC's institutional roots and areas of responsibility, see Gregory C. Chow, "Economic Planning in China," Princeton University Center for Economic Policy Studies Working Paper No. 219, June 2011, https://www.princeton.edu/ceps/workingpapers/219chow.pdf. See also Peter Martin, "The Humbling of the NDRC: China's National Development and Reform Commission Searches for a New Role Amid Restructuring," *China Brief* 14, No. 5, March 6, 2014, http://www.jamestown.org/programs/chinabrief/single/?tx_ttnews%5Btt_news%5D=42057&cHash=8866680e4f4e57e8997beb2cfbaa7aaa#.VsN6qMeMlFc.

98 "The Humbling of the NDRC."

3. **Reform the S&T research system,** especially the roles played by research institutes and university research units, through improved or new mechanisms for technology transfer and a better supporting system for the conduct of basic research.
4. **Strengthen and develop financial innovation mechanisms,** by scaling up venture capital investment, expanding the role of the capital markets to supporting technological innovation, and broadening indirect financing channels.
5. **Establish robust and institutionalized market-oriented mechanisms to promote innovation**, such as allowing the business sector a greater voice in government innovation decision-making, placing companies at the forefront of the commercialization of innovation, and paying more prominence to indirect regulatory mechanisms such as fiscal, taxation, and procurement policies.

Additional policy recommendations address the cultivation of human talent, international cooperation, and strengthening policy coordination and governance regimes.

This innovation-driven development strategy (IDDS) was officially promulgated by the Chinese authorities in May 2016 and provides a "top-level design and systemic plan" for China's innovation over next 30 years.[99] Specifically, the IDDS charts three stages of turning China into global innovation champion:

1. **Becoming an "innovative country" by 2020:** This means forging an innovation-friendly environment with improved intellectual property protection, better incentives, and a comprehensive set of policies and regulations.
2. **Joining the leading edge of advanced innovation countries by 2030:** The goal is for China to enter the ranks of the world's top tier of innovation leaders in select areas by the end of the next decade.
3. **Becoming a strong global innovation power by 2050:** The aspiration is for China to become the world's most advanced science and technology country by the middle of this century.

In a speech at the National Science, Technology, and Innovation Conference in May 2016, Xi explained the key themes of the IDDS, which included: 1) emphasizing the importance for China to develop original and cutting-edge innovation; 2) promoting the development of big science projects; 3) finding a better balance between the role of the state and market in innovation development; and 4) stressing that innovation was not simply about science and technology but also included the innovation of institutional mechanisms.[100]
The 13th FYP ushers China into a new phase of economic growth in which it faces increasingly challenging headwinds that will significantly affect the speed and nature of its economic and S&T development. The Chinese authorities acknowledge that the country is "entering a new normal of

[99] Ministry of Science and Technology, Outline of the National Strategy of Innovation-Driven Development, May 23, 2016, http://www.china.com.cn/zhibo/zhuanti/ch-xinwen/2016-05/23/content_38515829.htm.
[100] Xi Jinping's speech on "Struggle To Build a Strong Country in Science and Technology of the World" to the National Science and Technology Innovation Conference, Conference of Academicians of the Chinese Academy of Sciences and Chinese Academy of Engineering, and 9th National Congress of the Chinese Association for Science and Technology, Xinhua Domestic Service, May 31, 2016.

economic development and facing not only great strategic opportunities but complicated and tough challenges."[101] Technological innovation is being highlighted as a core component in the establishment of a new development model. The leadership is also keen to ensure that the long-range S&T objectives that it had set out in the MLP will be met by the end of this decade. The authorities point out that, "the five years from 2016 are a critical stage for building a moderately prosperous society in all aspects. The 13th Five-Year Development Plan will focus on realizing this goal."[102]

The authorities have highlighted a number of areas to which the 13th FYP will pay particular attention:

1. **Agriculture:** Support for key agricultural research in high-yield crops, the control and prevention of agricultural pollution, amelioration of heavy metal pollution, smart agricultural equipment, livestock, food processing, storage and transportation, and the efficient use of marine fisheries and forestry resources as well as research into livable towns.
2. **Energy:** Support for research into energy efficient and new energy technologies, including clean coal technologies, renewable energy, alternative energy, nuclear energy, and nuclear safety, as well as basic research into smart grid technologies.
3. **Industry:** Support for research in smart manufacturing, key and basic materials, new materials, precision and standard parts, manufacturing processes, major equipment, big data, cloud computing, broadband communications, network security, remote sensing, and navigation and positioning as well as the services generated from these technologies.
4. **Environment:** Support for environmental research into clean water, clean soil, ecological restoration, hazardous chemical management, deep water, oil, gas, and mineral resources exploration, waste material resources, marine engineering equipment, natural disaster monitoring and early warning systems, and basic research into climate change.
5. **Health:** Support for research on the prevention and control of major diseases, vaccine development, early drug development, the modernization of traditional Chinese medicine, reproductive health, in vitro diagnostics, biomedical materials, mobile health, bio-manufacturing of chemical products, and food safety.
6. **New-type urbanization:** Support for research into smart cities, green buildings and industrialization, transportation and smart transportation, rail transportation, public safety and emergency rescue.
7. **Basic research related to national strategic requirements:** Support for research into technologies deemed to be of strategic importance, especially through the use of large-scale research facilities, with the goal of achieving important technological breakthroughs in the next 10 years. This includes nanotechnologies, stem cells, proteins, child development and reproduction, quantum control, and climate change as well as deep space, deep sea, deep underground, and blue water research.
8. **Major international science projects:** Support for China's participation in major international S&T projects, especially those that assist China's integration into global innovation networks.[103]

[101] "Nation Outlines Goals for 13th Five-Year Plan," Xinhua, July 21, 2015.
[102] Ibid.
[103] "Notice on MOST Beginning 13th FYP National Key R&D Plan."

In addition, there is an emphasis on bioengineering, new materials including carbon fiber and graphene, and a 5G telecommunications network.[104]

The Made in China 2025 and Internet Plus Plans

The two major plans guiding Chinese industry for the next 10 years and beyond are the Made in China 2025 and the Internet Plus plans, released in May and July 2015, respectively (see Figure 6). Although not officially linked, taken together the plans are a response to broad trends in global manufacturing and IT development that has been dubbed "Industry 4.0" or the fourth industrial revolution after the steam, electrical power, and computer revolutions. Industry 4.0 leverages nine technology areas: autonomous robots, simulation, horizontal and vertical integration, the Internet of Things (IoT), cybersecurity, cloud computing, additive manufacturing, augmented reality, and big data and analytics.[105]

According to the Boston Consulting Group,

> Industry 4.0 will make it possible to gather and analyze data across machines, enabling faster, more flexible, and more efficient processes to produce higher-quality goods at reduced costs. This in turn will increase manufacturing productivity, shift economics, foster industrial growth, and modify the profile of the workforce–ultimately changing the competiveness of companies and regions.[106]

Both plans offer a mixture of new policy initiatives as well as a continuation of current measures, but much of the implementation remains undefined. The major new emphasis of both plans is a reliance on market principles instead of government direction to spur innovation. At the same time, both plans take a "megaproject" approach by prioritizing certain industries. Although specific implementation measures have not been announced, they will most likely include increased funding, perhaps through quasi-government investment funds, for mergers and acquisitions (M&A) as well as R&D, and policy measures to spur innovation by micro, small, and medium enterprises.

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[104] "十三五拟推重大工程创新计划 生物工程新材料等或入围" [The 13th FYP Mega Projects Innovation Plan Pushes Bioengineering and New Materials], Xinhua, June 17, 2015, http://news.xinhuanet.com/finance/2015-06/17/c_127924425.htm.

[105] The "Internet of Things" is the linkage of sensors and actuators embedded in physical objects through wireless networks, often using the same Internet protocol (IP) that connects the Internet. Michael Chui, Markus Löffler, and Roger Roberts, "The Internet of Things," *McKinsey Quarterly,* March 2010, http://www.mckinsey.com/insights/high_tech_telecoms_internet/the_internet_of_things.

[106] Michael RuBmann Lorenz, Markus Lorenz, Philipp Gerbert, Manuela Waldner, Jam Justus, Pascal Engel, and Michael Harnisch, "Industry 4.0: The Future Productivity and Growth in Manufacturing Industries," Boston Consulting Group, April 2015, 4.

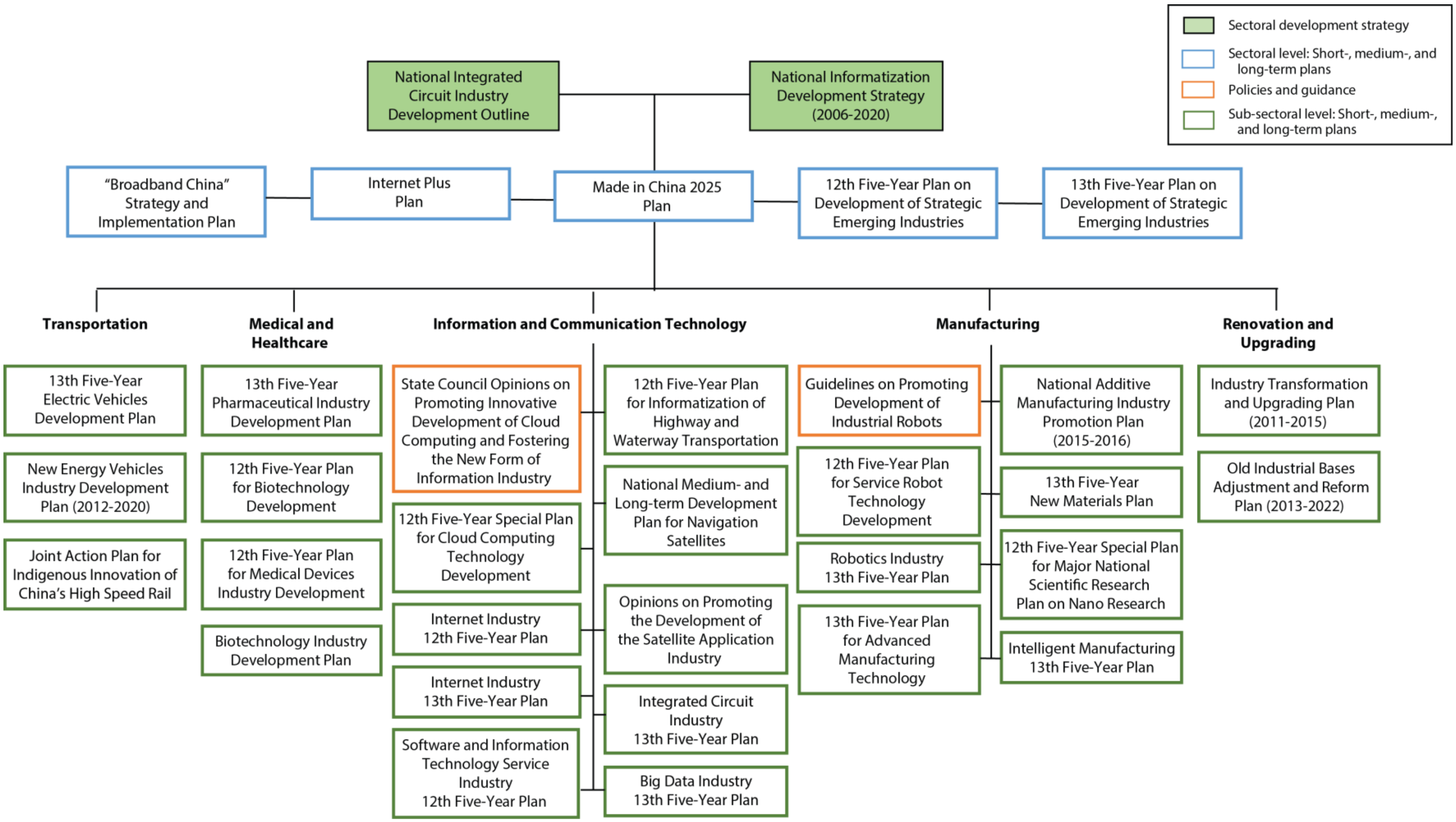

Figure 6. China's state strategies and plans for industrial development

Made in China 2025

Chinese leaders and policy planners recognize that the country's economic competiveness and national security rest on a strong and advanced manufacturing base.[107] China's competiveness, however, is being eroded as it becomes less attractive as the world's low-cost manufacturer. In response, global manufacturers have begun to look at ways of increasing productivity that depend less on where a company builds or sources its products and more on a holistic approach that takes into account other factors such as market size, logistics, and energy prices. As part of this approach, companies worldwide are increasingly turning to advanced manufacturing techniques and technologies to achieve the productivity gains and lower costs once associated with destinations such as China (see Box 1). Made in China 2025 appears to be a direct response to this trend.

Compared to the MLP and SEI, Made in China 2025 is different in several respects. First, it focuses on the entire manufacturing sector and industrial processes, not just innovation or a specific industry. Development of traditional industries and modern services are also promoted in the plan. Second, market mechanisms are more prominent than in the MLP or SEI. Enterprises, especially small and medium enterprises, are expected to play more important roles. Despite those differences, Made in China 2025 inherits some key components of these other plans. The megaproject format will still serve as a major mechanism to support S&T projects. Meanwhile, many of the industries listed as priorities in Made in China 2025 have also been included in the SEI.[108]

A State Strong Manufacturing Power Building Leading Small Group (国家制造强国建设领导小组) led by Vice Premier Ma Kai and administered by MIIT has been established to oversee the plan. It will coordinate efforts to improve China's manufacturing sector across state agencies and among all levels of government as well as to review major plans, policies, projects, and important work.[109]

Made in China 2025 Origins

Made in China 2025 was first proposed in a government work report by Premier Li Keqiang in March 2015 and is the country's first ten-year blueprint to empower China through manufacturing by encouraging innovation and raising efficiency. This initiative is based on research results from a joint project begun in 2013 by the Chinese Academy of Engineering (CAE) and MIIT that sought ways to raise the quality of Chinese products and reshape the country as a manufacturing power.[110] The project concluded that manufacturing is essential for China to build itself into a world power. However, China's manufacturing sector is facing severe internal and external challenges.

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[107] "中国制造 2025": 建设制造强国之路" ["Made in China 2025": The Way to Become A Manufacturing Power], Xinhua, March 23, 2015, http://news.xinhuanet.com/comments/2015-03/23/c_1114725622.htm.

[107] Scott Kennedy, "Made in China 2025," Center for Strategic & International Studies, June 1, 2015, http://csis.org/publication/made-china-2025.

[108] State Council, "国务院关于印发《中国制造 2025》的通知" [Made in China 2025 Plan Unveiled to Boost Manufacturing], May 8, 2015, http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm.

[109] "国办成立国家制造强国建设领导小组 马凯任组长" [State Council Establishes State Strong Manufacturing Power Building Leading Small Group Headed by Ma Kai], 人民网 [People's Net], June 24, 2015, http://politics.people.com.cn/n/2015/0624/c1001-27201253.html.

[110] "李克强的王牌计划：中国制造 2025" [Li Keqiang's Flagship Plan: Made in China 2025], ifeng.com, March 11, 2015, http://finance.ifeng.com/a/20150311/13545234_0.shtml.

Box 1. Advanced Manufacturing

Advanced manufacturing, defined "as a set of highly flexible, data-enabled, and cost-efficient manufacturing processes," and called "Industry 4.0" by some, offers the potential to reduce production costs by 20−40 percent by harnessing the power of information technology to advance manufacturing processes. Characterized as a fourth wave of industrial advancement that follows the steam power revolution, the widespread use of electricity, and the adoption of automation, this new wave will feature interconnected networks of sensors, machines, workpieces, and IT systems, making it possible ""to gather and analyze data across machines, enabling faster, more flexible, and more efficient processes to produce higher-quality goods at reduced costs."[1]

According to the Boston Consulting Group, advanced manufacturing will lay "the foundation for the adoption of new business models, production processes, and other innovations."[2] Advanced manufacturing technologies can enable companies to customize products, make smaller batches for specific customers, rapidly adjust production lines to accommodate for design changes, and shorten R&D cycles by generating prototypes faster. It can also stimulate innovation by "allowing the creation of new kinds of products that are not cost effective when using conventional processes."[3]

Advanced manufacturing leverages several trends: a larger role for IT in the manufacturing process; increasing use of modeling and simulation to improve manufacturing processes; acceleration of innovation in global supply chain management; increasing flexibility to meet customer needs; and more sustainable manufacturing. These trends will be expressed through the adoption of technologies that link hardware, software, businesses, and customers through networking and other information technologies. Technologies that figure large in this vision include:

- Big Data to collect data from multiple sources such as production and customer management systems to improve quality control, save energy, and improve equipment service.
- Industrial IoTs to connect sensors and field devices so that they can interact in order "to decentralize analytics and decision making, enabling real-time responses."
- Cloud computing to increase data sharing across the usual boundaries to "enable more data driven services for production systems."
- Autonomous robots, which will enable "manufacturers to cost-effectively produce items at smaller scale while also enhancing quality."
- Integrated computational materials engineering to build and test products virtually before they are manufactured to enable companies to build products "better, faster, and cheaper."
- Digital manufacturing to virtually create production lines in order to optimize work flow.
- Industrial Internet and flexible automation to facilitate communication between manufacturing equipment lines in order to automatically adjust production.
- Additive manufacturing to make small batches of products and reduce material waste.
- Cybersecurity to protect these increasingly interconnected industrial processes from computer network attack.[4]

A 2012 assessment of global advanced manufacturing trends argues that the coordinated use of these technologies forms "an enterprise-level concept of advanced manufacturing" where advances take place "through tighter integration of R&D and production, mass customization, increased automation, and a focus on the environment without increasing costs or sacrificing performance."[5] These trends will push advanced manufacturing toward "new frontiers," "with automated processes based on sensors, robots, and condition-based systems reducing the need for human intervention, while providing information to drive process improvement."[6]

Notes

1. Michael RuBmann Lorenz, Markus Lorenz, Philipp Gerbert, Manuela Waldner, Jam Justus, Pascal Engel, and Michael Harnisch, "Industry 4.0: The Future Productivity and Growth in Manufacturing Industries," Boston Consulting Group, April 2015, 4.
2. Ibid., 12.
3. Harold L. Sirkin, Michael Zinser, and Justin R. Rose, "Why Advanced Manufacturing Will Boost Productivity," Boston Consulting Group, 2015, 2.
4. Sirkin, Zinser, and Rose, "Why Advanced Manufacturing Will Boost Productivity," 2; Lorenz et al., "Industry 4.0: The Future Productivity and Growth in Manufacturing Industries,"4–7.
5. Stephanie S. Shipp, Bhavya Lal, Justin A. Scott, Christopher L. Weber, Michael S. Finnin, Meredith Blake, Sherrica Newsome, and Samuel Thomas, "Emerging Global Trends in Advanced Manufacturing," Institute for Defense Analyses, March 2012, iv.
6. Ibid., vi.

Internally, although China's manufacturing sector is the largest in the world, it is still weak in terms of core technology and innovation and is perceived as producing low-quality goods and lacking globally recognized brands. China's manufacturing sector is also inefficient and a major polluter. The sector's industrial structure also suffers from decades of top-down central planning that means that it does not respond efficiently to market forces and suffers from excess capacity.[111]

Externally, China is being squeezed out of the low-end market by low-cost competitors such as Vietnam. At the same time, Chinese manufacturers do not have the technological sophistication of competitors from advanced industrialized economies. Moreover, manufacturing has become a new focus of global economic competition, with developed countries introducing strategies and plans to revitalize their manufacturing sectors. Most notable is Germany's "Industry 4.0" plan from which the Made in China 2025 plan draws inspiration.[112] The main difference between China's plan and the plans of developed countries, however, is that while the manufacturing base of countries such as the United States and Germany is already developed, the development level of China's manufacturing sector remains uneven. As a consequence, China is faced with the daunting challenge of upgrading many backwards industries to current levels of manufacturing before it can aspire to tap the potential of a potentially new manufacturing revolution.[113]

Made in China 2025 Goals

The Made in China 2025 plan outlines a three-step strategy for China to comprehensively upgrade its industrial economy and achieve its stated goal of becoming a world-leading manufacturer by the one-hundredth anniversary of the founding of the People's Republic of China in 2049. The first step is to make significant advances in innovation as well as manufacturing efficiency to realize basic industrialization by 2025. The second step is to be able to compete with the developed manufacturing powers by 2035. The last step is to be a leading world manufacturer. To achieve this goal, Made in China 2025 sets up clear principles, tasks, tools, and focused sectors.[114]

The plan's guiding principles are to establish innovation-driven manufacturing, emphasize quality over quantity, achieve green development, optimize the structure of Chinese industry, and nurture human talent. The plan states that a number of favorable policies will be introduced to deepen institutional reforms, strengthen financial and tax support, complete a multi-level talent training system, facilitate small and micro enterprises, and improve organization and implementation mechanisms.[115]

[111] "《中国制造 2025》解读之四：我国建设制造强国的任务艰巨而紧迫" [Interpret 'Made in China 2025': The Task Is Arduous and Urgent], MIIT website, May 19, 2015, http://www.miit.gov.cn/n11293472/n11293832/n11294042/n11481465/16595213.html.

[112] "《中国制造 2025》解读之三：我国制造业发展面临的形势和环境" [Interpret "Made in China 2025": Situation and Environment Facing China's Manufacturing Industries], Xinhua, May 19, 2015, http://news.xinhuanet.com/finance/2015-05/19/c_127818527.htm.

[113] "中国的工业 4.0 计划，国务院印发《中国制造 2025》" [China's Industry 4.0 Plan, The State Council Issued "Made in China 2025"], sohu.com, May 20, 2015, http://auto.sohu.com/20150520/n413369391.shtml.

[114] "《中国制造 2025》解读之六：制造强国"三步走"战略" [Interpret "Made in China 2025": "Three-Step" Strategy to Become A Manufacturing Power], MIIT website, May 19, 2015, http://www.miit.gov.cn/n11293472/n11293832/n11294042/n11481465/16595227.html.

[115] "Made in China 2025 Plan Unveiled to Boost Manufacturing."

Nine tasks have been identified as leading priorities:

1. Enhance the national innovation capability in manufacturing.
2. Advance integration of information technologies and industrialization.
3. Strengthen industrial capability in core components, advanced basic technologies, key basic materials, and the industrial technology base.
4. Enhance quality and brand-building.
5. Push green manufacturing.
6. Vigorously promote development in key areas.
7. Further promote structural adjustment of the manufacturing sector.
8. Actively develop service-oriented manufacturing and producer services.
9. Raise the level of the internationalization of manufacturing development.

To fulfill these tasks, the plan introduces five sub-plans intended to facilitate government involvement when market mechanisms alone are insufficient:

1. **Manufacturing innovation center (industrial technology research base) construction plan:** Establish 15 manufacturing innovation centers by 2020 and 40 by 2025 to conduct R&D on basic and common technologies for key industries.
2. **Intelligent manufacturing plan:** Significantly improve the level of intelligent manufacturing in key areas by 2020 through the integration of new information technologies and equipment innovation.
3. **Core industrial capability strengthening plan:** Support development in core components and industrial technology and raise the ratio of domestic core components and materials to 40 percent by 2020 and 70 percent by 2025 of overall supply, which is currently dominated by foreign products with more than 80 percent in certain areas.[116]
4. **Green manufacturing plan:** Implement a special technological transformation project in traditional manufacturing sector and cut emissions by 20 percent by 2020, compared to the 2012 level.[117]
5. **High-end equipment innovation plan:** Establish independent design and manufacture of advanced equipment capabilities in aviation, transportation, marine engineering, manufacturing, nuclear, and healthcare by 2020.

[116] Zhu Minghao, "实现制造强国须先弥补基础短板" [Need to Work on Core Components to Become a Manufacturing Power], 中国工业评论 [*China Industry Review*], August 3, 2015, http://www.chinaeinet.com/article/detail.aspx?id=10690; Huang Xin, "夯实基础 有大变强" [Lay a Solid Foundation to Grow Stronger], 经济日报 [*Economic Daily*], February 26, 2014, http://paper.ce.cn/jjrb/html/2014-02/26/content_189990.htm.
[117] Manufacturing Power Strategic Research Committee, *Research on the Manufacturing Power Strategy* (Beijing: Publishing House of Electronics Industry, 2015), 263–77.

Made in China 2025 Industry Support

In addition to the five sub-plans, the plan also prioritizes 10 industrial sectors for policy and funding support. Each is discussed in further detail below. The 10 sectors are:

1. New generation information technology
2. Automated machine tools and robotics
3. Space and aviation equipment
4. Maritime equipment and high-tech shipping
5. Modern rail transportation equipment
6. New energy vehicles and equipment
7. Power generation equipment
8. Agricultural equipment
9. New materials
10. Biopharma and advanced medical products

NEW GENERATION INFORMATION TECHNOLOGY INDUSTRY

Efforts to promote the next generation of information technology will focus on three main technology areas: microchips and associated equipment, information and communication equipment, and processor systems and industrial software.

1. **Microchips and associated equipment:** China has identified microchips as a critical foundational component of its high-tech industrial economy. Microchips, also known as semiconductors or integrated circuits, are small electronic devices made up of a collection of resistors, capacitors, and transistors on a small chip. Microchips are used in nearly all modern electronic devices and have become the foundation of the computing revolution.

   The plan will focus on raising the technological level of Chinese microchips and improving core intellectual property and design tools. Prioritization of microchip research will be on making breakthroughs in core chips related to information security and the electronics industry and promoting the use of domestic chips. It will also focus on mastering high precision packaging and additive manufacturing technologies in order to improve the independent development capability of the packaging industry.

2. **Information and communication equipment:** This area will focus on enabling Chinese industry to master technologies related to new types of computing, high-speed Internet, advanced storage, and systems-level security. It will have the goal of making breakthroughs in 5G communications technology, processors and servers, ultra-high-speed, large-capacity intelligent optical transmission technologies, and "future network" (未来网络) technologies. Industry will pursue advancements in quantum computing and neural networks and will research and develop high-end servers, large capacity storage, new types of routers, new types of intelligent terminals, next-generation base stations, and network security equipment.

3. **Processor systems and industrial software:** The focus will be on developing operating systems in information security and making breakthroughs in intelligent design and simulation, and industrial software, such as manufacturing IoT and big data for industry. Industry will be encouraged to develop high-end autonomous control industrial platforms and related application software and establish improved integrated standards for industrial software.

HIGH-END NUMERICAL CONTROL EQUIPMENT AND ROBOTICS

The high-end numerical control equipment domain will focus on developing precision, high-speed, highly efficient flexible computer numerical control and basic manufacturing equipment and integrated manufacturing systems. It will seek to increase the speed of numerical control and additive manufacturing technologies and equipment. With reliability and precision as the focus, industry will develop high-end numerical control equipment, servomotors, bearings, and gratings.

China's principal goals in the robotics area are to actively develop new products, promote standardization, modular development, and expand market applications of robotics in the automobile, mechanical, electronics, hazardous materials, national defense, chemical, light, healthcare, and domestic services industries. Another key goal is to make breakthroughs in the integrated design and manufacturing of robot bodies, reducers, sensors, servomotors, control equipment, and drivers.

AVIATION AND SPACE

China's goals for its aviation industry are to speed up the development of large commercial single-aisle aircraft and to begin R&D of wide-body aircraft. It will encourage foreign participation in the R&D of large helicopters and promote regional aircraft, helicopter, unmanned aerial vehicles, and general aviation industrialization. The industry will seek to establish an independent capability to manufacture advanced engines and make breakthroughs in high thrust to weight ratio and advanced turboprop engines and high bypass ratio turbofan engines. It will also strive to develop advanced mechanical equipment and systems and form a comprehensive research, development, and production chain.

China's space industry, on the other hand, will develop a next generation of launch vehicles and heavy launch vehicles. It will expedite the development of national civil-use space infrastructure, new types of satellites, air-space-ground broadband Internet systems, long-term, persistent satellite remote sensing, communications, and navigation technologies, promote human spaceflight and lunar exploration, and develop deep space exploration at a moderate pace. While no definition has been given as to what "moderate pace" means, it could suggest that priority is being placed on remote sensing, communication, and navigation over manned space flight and lunar exploration.

MARINE ENGINEERING EQUIPMENT AND HIGH-TECHNOLOGY SHIPPING

China aims to develop deep-sea exploration and resource extraction, and marine industrial support equipment. It will promote the development of deep sea stations and large-scale floating structures and will form a marine engineering equipment testing, monitoring, and appraisal capability to improve marine resource use. The industry will also focus on making breakthroughs in luxury cruise liner design and manufacturing, improving the international competitiveness of its liquid natural gas carriers, and mastering the integration of components and equipment.

ADVANCED RAIL TRANSPORTATION

China's goal for its railway industry is to quicken the application of new materials, new equipment, and new processes. It will seek to achieve key breakthroughs in safety and environmentally friendly and digitally networked technologies and will research and develop advanced and reliable products and products that are light, modularized, and pedigreed. The ultimate goal is to develop a world-class rail transportation system that occupies the higher end of the global industrial chain and is environmentally friendly and able to meet customer needs.

ENERGY EFFICIENT AND ALTERNATIVE ENERGY VEHICLES

China will continue to support electric vehicles and fuel cell vehicle development and work to master low carbon, informationized and intelligent technologies. It will improve electric propulsion, drive motor, high efficiency internal combustion engines, advanced transmissions, lightweight materials, and intelligent controls.

ELECTRICAL POWER GENERATION EQUIPMENT

China will promote large-scale clean coal technologies, high-capacity hydropower plants, nuclear power plants, and heavy-duty gas turbines. It will promote the development of alternative energies, renewable energy technologies, advanced energy storage devices, and smart electrical grids at the transmission and end-user levels. It will also promote the manufacture of high-power electrical devices and high-temperature materials.

AGRICULTURE

China will focus on the development of grains, cotton, oil, and sugars and other staple foods as well as economic education on advanced equipment used in farming and on the management, collection, transportation, and storage of agricultural products. It will quicken the development of large tractors and farm implements, large-scale high-efficiency combines, and their core technologies. and improve the ability of agricultural equipment to collect information, make smart decisions, and work with greater precision.

NEW MATERIALS

New materials can allow technologies to be more efficient or faster, or to add new capabilities. Development of new materials will focus on specialty metals, high-performance structural materials, functional polymers, inorganic nonmetals, and advanced composites. The plan will accelerate the development of advanced melting, solidification molding, vapor deposition, profile processing, the efficient synthesis of new materials, and other key technologies and equipment. It will strengthen basic research and breakthrough industrialization bottlenecks. The development of dual-use materials is highlighted, as well as the need to speed up their transformation into products and to pay attention to disruptive materials such as superconductors, nanomaterials, graphene, and biological materials.

BIOMEDICAL AND HIGH-PERFORMANCE MEDICAL EQUIPMENT

The plan calls for the development of pharmaceuticals, traditional Chinese medicine, and biological technologies for major diseases. This includes new mechanisms and targets for chemical agents, antibody drugs and antibody conjugates, new structures of protein and peptide drugs, new vaccines, and clinical medicines. It will also focus on the development of imaging equipment, medical-use robots, biodegradable stents, wearable medical products, telemedicine, bio 3D printing, and stem cell technologies and applications.

The Internet Plus Plan

Another major initiative to transform Chinese industry is the Internet Plus plan, which is intended to encourage the development of e-commerce, industrial networks, Internet banking, and to increase the international presence of Chinese Internet companies. The official purpose of Internet Plus is “to more deeply integrate the internet with the economy and society” by fostering new industries and public services.[118] Similar to the Made in China 2025 plan, Internet Plus will be led by an inter-ministerial group and an advisory committee.

Internet Plus has four foci. The first is to transform China's traditional, labor-intensive manufacturing sector into an IT-driven base that is more efficient and can expand its market reach globally. To enable this transformation, a second focus is on increasing the role of small and micro enterprises in developing platforms and applications by creating a policy environment that is more favorable to these types of companies. A third focus is to expand access to credit to these smaller companies by encouraging e-banking and crowd-sourced funding. The fourth focus is on expanding and improving fixed and broadband communication networks, especially in rural areas and less-developed western regions of the country. Underlying these initiatives is a commitment to let market forces guide the implementation of Internet Plus rather than relying excessively on government fiat.

Transforming Manufacturing

The initiative to transform manufacturing is based on the development of new market-oriented, Internet-based products and business models. A particular emphasis of Internet Plus is integrating nine broad economic sectors with mobile Internet, cloud computing, big data, and the IoT to improve R&D and increase access to consumers through the use of crowd-sourced design, cloud manufacturing, and business-to-business platforms.

The Internet Plus plan will require industries to utilize cloud and big data platforms and wireless sensor networks. The plan seeks to enhance the ability of public cloud services to migrate industry to the cloud, accelerate content delivery networks, and optimize data center layout. In doing so, it will emphasize industrial cloud innovation test sites and a number of industrial cloud experimental centers.[119]

This focus on developing cloud computing, big data, and the IoT also requires the development of component technologies. China has set its sights on making breakthroughs in core chip technologies; addressing weaknesses in the high-end server, high-end storage device, database and middleware industries; and accelerating the development and application of cloud operating systems, industrial control real-time operating systems, intelligent terminal operating systems, and sensors and human-computer interaction technologies.

The outsourcing of critical business processes to third parties raises concerns about the security of cloud computing.[120] The Chinese government appears to recognize this risk and plans to strengthen the security of information network infrastructure and personal information protection. The plan calls for the implementation of national information security projects, development of

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[118] State Council, "国务院关于积极推进"互联网+"行动的指导意见" [State Council Guiding Opinions Governing "Internet Plus" Activities], July, 1, 2015, http://www.gov.cn/zhengce/content/2015-07/04/content_10002.htm.

[119] "国务院关于信息化建设及推动信息化和工业化深度融合发展工作情况的报告" [State Council Report on Informationized Building and Promoting the Integration of Informationization and Industrialization Development Work Situation], June 29, 2015, MIIT website, http://www.miit.gov.cn/n11293472/n11293832/n13095885/16682295.html.

[120] "Guide to Cloud Computing for Manufacturing," Search Manufacturing ERP, accessed September 14, 2015, http://searchmanufacturingerp.techtarget.com/guide/SearchManufacturingERPcom-Cloud-Guide.

Internet security application demonstration projects, and the upgrading of security standards for core technologies. It will also improve network security monitoring.

Increasing the Role of Small and Micro Enterprises

Increasing the role of small and micro enterprises is a policy reversal from the Hu Jintao administration's emphasis on growing the role of large state-owned enterprises (SOEs).[121] With this new emphasis, the Xi Jinping administration appears to be following the lead of other countries in recognizing that established companies are often not well suited to recognize market opportunities and develop innovative—especially disruptively innovative—products. To assist smaller companies, the plan will take steps to improve the policy environment for human resources, capital allocation, industrial parks, and taxation to make it easier for small and micro enterprises to be founded and to operate. The Internet Plus plan also encourages successful Internet and communication technology companies to provide technology and management expertise to small enterprises through technology incubators, S&T parks, and demonstration bases and by improving access to crowd-sourced design and funding.[122]

An area of increased attention will be the creation and protection of IPR for small and micro enterprises. The plan will support the creation of an open-source software community through the support of independent R&D by enterprises and national S&T plans. It will guide educational institutions, social organizations, enterprises, and individuals in initiating open-source projects and participating in international projects. It will also encourage enterprises to build an ecosystem for open-source development to promote open-source standards and IPR.

Companies with a competitive advantage will be encouraged to acquire foreign companies or to pursue joint ventures with them to sell overseas. The plan will fully utilize government and industry alliances and industry associations. It will encourage agencies to provide information consultation, legal assistance, tax advice, and other services to enterprises to expand overseas markets, and it will support industry associations, industry alliances, and companies to jointly promote Chinese technology and Chinese standards to drive overseas application.

Expanding Access to Capital

To facilitate access to capital for these new small and micro enterprises, the government plans to encourage Internet banking. Small and micro enterprises, according to 2013 State Council statistics, created 80 percent of new jobs in China, account for 60 percent of GDP, and contribute up to 50 percent of tax revenue in China. However, they account for less than 25 percent of total lending from China's state-owned banks.[123] This lack of available credit has forced SMEs to resort to nonbank institutions for credit, including shadow banks that operate outside of government regulations. The bias against lending to SMEs in China not only results from government regulations

[121] Michael Wines, "China Fortifies State Businesses to Fuel Growth," *New York Times*, August 29, 2010.

[122] "China to Step Up Integration of Information, Industry: Minister," Xinhua, June 29, 2015, http://en.people.cn/n/2015/0629/c202936-8912767.html; "Cabinet Stresses 'Internet Plus' Strategy," CCTV.com, June 24, 2015, http://english.cntv.cn/2015/06/24/ARTI1435154475044265.shtml; State Council, "Full Text: Report on the Work of the Government (2015)," March 16, 2015, http://english.gov.cn/archive/publications/2015/03/05/content_281475066179954.htm.

[123] Kwong Man-ki, "China's Cabinet Calls for Easier Access to Credit for Small Firms," *South China Morning Post*, July 16, 2013, http://www.scmp.com/business/banking-finance/article/1283496/chinas-cabinet-calls-easier-access-credit-small-firms.

that have strict loan to deposit ratios and high reserve requirements, but also from 1) government policy that directs credit to certain industries; and 2) biases toward SOEs and against lending to private corporations. In contrast with SOEs, which usually are better credit risks because of implicit state guarantees and favored market positions, SMEs often have little collateral and inadequate credit histories. This last phenomenon is exacerbated by a lack of loan officers who can accurately judge the creditworthiness of loan applicants.[124]

Expanding and Improving Communication Networks

The plan's fourth goal is to increase the market for these new technologies by establishing high-speed broadband networks that cover smaller towns and rural areas, especially in western China. The central government will continue to develop its 4G communications network while speeding up research on a 5G mobile communications network. It will also continue plans for a national data center; establish a large cloud computing center; improve the websites of SMEs, governments, and public service platforms; and support the development of IPv6.[125]

China plans to accelerate the implementation of its "broadband China"（宽带中国）strategy by implementing a new generation of national information infrastructure projects to promote broadband fiber-optic networks and upgrade its mobile communications network. With this plan, China also seeks to substantially increase access, reduce fees, and improve revenue mechanisms to support the construction of broadband in rural and remote areas. The country will also improve the Beidou satellite navigation system's global service capabilities and accelerate the commercial deployment of next-generation Internet.

The government has two timelines for the achievement of these goals, with the final timeline coinciding with the end of the first phase of the Made in China 2025 plan. By 2018, the Internet Plus plan intends to:

1. Improve the quality and efficiency of economic development by promoting the development of the Internet in manufacturing, agriculture, energy, and environmental protection; improve the efficiency of labor; and promote the development of e-commerce and e-finance.
2. Improve public services through the development of Internet applications for healthcare, education, and transportation.
3. Integrate the industrial base with network architecture, improve fixed and mobile broadband networks, and accelerate the development of the next generation of Internet and the IoT, cloud computing, and artificial intelligence.
4. Stimulate the development of the Internet by making more data publicly available, improving standards, and improving the laws and regulations of the financial credit system.

By 2025, the goal is to have a sound, collaborative Internet Plus-manufacturing ecosystem that is an important source for economic and social development.

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[124] See Kellee S. Tsai, "Financing Small and Medium Enterprises in China: Recent Trends and Prospects Beyond Shadow Banking," Hong Kong University of Science and Technology Institute for Emerging Market Studies, May 2015; and Douglas Elliot, Arthur Kroeber, and Yu Qiao, "Shadow Banking in China: A Primer," Brookings Institution, March 2015.

[125] Internet Protocol version 6 (IPv6) is the most recent version of the addressing protocol that provides a unique identifier for each computer on a network. The new protocol will increase the number of available IP addresses, enabling, among other things, continued expansion of the Internet.

Assessing the Made in China 2025 and Internet Plus Plans

China's commitment to leveraging the trends of advanced manufacturing to reposition itself away from low-cost manufacturing and towards the manufacture of more value added products raises questions about their originality and effectiveness. Although both the Made in China 2025 and Internet Plus plans talk of emphasizing the role of the market in determining technology development and of a strong sector made up of small and micro businesses, they carry many of the trappings of conventional state-directed planning. This appears to be especially present in the role of new industrial investment funds. Ostensibly operating on market principles, these funds are mainly financed by government entities and SOEs, raising questions about their autonomy from government leaders who may be more inclined to interfere with market processes. The quasi-governmental nature of these investment funds raises questions about whether these new funding mechanisms have been established to get around WTO restrictions on the direct funding of certain industries. Moreover, the plan calls for national development banks to expand credit in unspecified ways to manufacturing companies.

China's commitment to supporting small and micro enterprises may also be less than it seems. The Made in China 2025 plan speaks of larger enterprises supporting the development of small and micro enterprises, but it does not necessarily discuss fostering the latter to achieve a market niche of their own. Instead, it may be intended for these small and micro enterprises to help facilitate the competiveness of larger corporations.

China's adherence to its indigenous innovation policy is highlighted in the Made in China 2025 plan with its mention of "self-sufficiency and control of high-tech manufacturing platform software and major application areas," and the creation of industrial standards and security testing. The plan also specifies that Chinese firms are to handle the majority of local infrastructure development by 2025.

In sum, the Made in China 2025 and Internet Plus plans appear geared towards creating national champions. This raises the concern that the modernization of China's manufacturing base will involve tolerating Western companies while seeking ways to replace them with domestic companies. To date, this has mainly occurred on the low end of the technology scale but, if successful, could result in Chinese industry being more capable of competing with the United States at the upper end of manufacturing, where value-added may be more important than cost. Ultimately, however, China's success at implementing the Made in China 2025 and Internet Plus plans rests on its ability to develop a strong IT industry.[126]

China may make genuine progress in modernizing its manufacturing sector, but the United States can still maintain its lead, even if the gap is narrowed. The United States remains a strong manufacturing power with $3.4 trillion worth of goods manufactured annually, three-quarters of which is consumed domestically.[127] In fact, the Boston Consulting Group argued in 2013 that the United States is now "one of the lowest-cost countries for manufacturing in the developed world" and is

[126] Stephanie S. Shipp, Bhavya Lal, Justin A. Scott, Christopher L. Weber, Michael S. Finnin, Meredith Blake, Sherrica Newsome, and Samuel Thomas, "Emerging Global Trends in Advanced Manufacturing," Institute for Defense Analyses, March 2012, 29.
[127] Boston Consulting Group, "US Manufacturing Nears the Tipping Point," March 2012, 4.

on the verge of an advanced manufacturing "renaissance" where worker productivity, supply chain, and logistical advantages may lead companies to begin locating or relocating manufacturing facilities to the United States.[128] Boston Consulting Group identifies seven industrial sectors where rising costs in China will make it more economical to shift manufacture of goods consumed in the United States to the United States: 1) computers and electronics; 2) appliances and electrical equipment; 3) machinery; 4) furniture; 5) fabricated metals; 6) plastics and rubber; and 7) transportation goods.[129] These industries account for nearly $2 trillion of US consumption and nearly $200 billion in imports from China.[130] Boston Consulting Group estimates that a resurgent US manufacturing sector could reduce the import of goods in these seven industries by 10 to 30 percent from China by the end of the decade, adding $20 billion to $55 billion to the US economy. This relocation, coupled with improved competitiveness with Western Europe, could create 2–3 million jobs in the United States.[131]

If realized, these predictions could mean that United States manufacturing not only survives but also prospers despite new competition from Chinese companies. It will mean, however, that US companies must 1) maintain a commitment to innovation that keeps them ahead of foreign competition; and 2) treat the manufacturing process as an integrated whole that emphasizes more than just labor costs. It may also mean that although some manufacturing returns to the United States, companies may still retain their China-based factories to serve the Chinese domestic market. In this case, the global manufacturing industry could see a multipolarization of high-end manufacturing where companies establish factories in large markets to service regional customers rather than using one country as a global manufacturing base.

Science and Technology in China: A Roadmap to 2050

In 2007, the CAS embarked on a two-year study to examine long-term S&T trends to the middle of this century and assess their implications for China's development. The project, "Science and Technology in China: A Roadmap to 2050" (中国的科学技术:通向 2050 的路线图), had three overarching objectives: 1) to ensure economic growth and national competitiveness; 2) to promote social harmony; and 3) to nurture sustainability between humankind and nature.

CAS President Lu Yongxiang was the mastermind behind the project and provided its strategic guidance. The timing for the study was surprising, as the MLP had only been drawn up a year earlier and provided a detailed path for China's S&T development until 2020. Lu has explained that the 2050 Roadmap originated from discussions at CAS about its long-term S&T strategic development priorities. There was a realization that the planning was insufficiently long range, especially on critical S&T challenges that were at early stages of research, such as nuclear power.[132]

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[128] Harold L. Sirkin, Michael Zinser, and Justin Rose, "Behind the American Export Surge: The US as One of the Developed World's Lowest-Cost Manufacturers," Boston Consulting Group, August 2013, 3.
[129] Boston Consulting Group, "US Manufacturing Nears the Tipping Point," 8.
[130] Ibid., 9.
[131] Ibid., 3.
[132] Speech by Lu Yongxiang Lu at the first high-level workshop on "China's Science and Technology Roadmap for Priority Areas to 2050," organized by the Chinese Academy of Sciences, October 2007, which was adapted to become the foreword for the published version of the study. See Lu Yongxiang, chief ed., *Science and Technology in China: A Roadmap to 2050: Strategic General Report of the Chinese Academy of Sciences* (Beijing and Heidelberg: Science Press and Springer, 2010), vi–xii.

CAS mobilized the extensive intellectual resources of its workforce, which boasted of more than 100 of the country's foremost research and development institutes. More than 300 CAS experts were involved in the project, including 60 academicians, and their work covered eight broad categories:

1. Sustainable energy and resources
2. Environmentally friendly advanced materials and intelligent manufacturing
3. Ubiquitous information networking
4. High-value agriculture and biology
5. Ecological and environmental conservation
6. Space and maritime exploration and development
7. Healthcare
8. National and public security

The roadmap put forward twenty-two S&T initiatives that it deemed to be of strategic importance to China's long-term development. Six are related to China's international competitiveness, including the production of high-quality raw materials and the development of exascale high-performance computing capabilities. Seven concern China's sustainability, such as the development of geothermal power generation, next-generation nuclear energy production, and research into stem cell and regenerative medicine. Two initiatives focus on national and public security, which relate to space situational awareness and social computing and parallel management systems. Four address basic science efforts that are likely to produce transformative breakthroughs, such as in the exploration of dark matter and dark energy, artificial life, and synthetic biology. The final three were in highly promising emerging areas of cross-disciplinary research that include nano-science, mathematics and complex systems, and space exploration.

While the 2050 Roadmap was primarily intended for the academy's own long-term planning, Lu and the CAS leadership also likely saw the project as a way to maintain its hard-won efforts to remain a close advisory body to the Chinese leadership on S&T development. The chief rival to CAS for the ear of the leadership on S&T matters is MOST, which was responsible for the drafting and implementation of the MLP.[133] Guo Huadong, a senior CAS official and head of the research team on the space technology strategy segment of the 2050 Roadmap, said that the study was "not an official plan, but more of a strategic suggestion to the decision makers."[134] While Guo was referring to his space report, the comment was also reflective of what the CAS leadership may have intended for the overall roadmap.

The 2050 Roadmap received substantial media coverage when it was issued in 2010; however, its overall policy impact appears to be modest. In speeches or public deliberations on S&T matters, senior officials have only occasionally mentioned the roadmap. There has also been little reference to the roadmap in major S&T policy documents like with the 12th or 13th FYPs or the Made in China 2025 plan. This is despite the fact that some of the key areas of the 2050 roadmap address

[133] Richard P. Suttmeier, Cong Cao, and Denis Fred Simon, "China's Innovation Challenge and the Remaking of the Chinese Academy of Sciences," *Innovations* 1 (summer 2006): 78–97.
[134] "China 'May' Send Manned Flights to Moon, Set up Base by 2030," *China Daily*, June 12, 2009.

current high priorities such as space and oceanic exploration and development, advanced manufacturing, and information networking.

Challenges and Recent Reforms to China's Science and Technology System

Despite impressive progress in China's S&T catching up to Western countries over the past two decades, the country's leadership is deeply concerned that there is too much duplication, insufficient original innovation, and chronic waste.[135] When policymakers reviewed the MLP in 2012 after its first six years, there was considerable disappointment expressed that many of the weaknesses that plagued the S&T system had not been resolved, but rather, ignored, because of the plentiful supply of funding.

Xi Jinping's first major policy speech on S&T reform came at a joint meeting of the CAS and CAE in June 2014 where he expressed a dim view about the state of the country's innovation capabilities. He pointed out that "China's foundation for science and technology innovation is still not firm. China's capability for indigenous innovation, and especially original innovation, is still weak. Fundamentally, the fact that we are controlled by others in critical fields and key technologies has not changed."[136]

In a diagnosis of what Xi referred to as "the chronic malady of impotence, obstruction, and gridlock in converting S&T achievements into actual productive forces," a key bottleneck is that "the link between innovation and conversion is insufficiently tight at every phase." Xi said that the only way to overcome this fundamental problem was that "reform of the science and technology system must be deepened. All ideological barriers and institutional obstructions that constrain scientific innovation must be broken down." Xi gave a list of structural and policy reform measures that were needed:

- Place STI at the "core of overall national development and accelerate the formulation of top-level designs that promote the strategy of innovation-driven development."
- Remake the national S&T innovation strategy.
- Overhaul the structure and process for resource allocations to support S&T development.
- Strengthen unified planning and coordination of STI efforts.
- Tackle fragmentation, especially of stove-piping and overlapping redundancies.
- Improve the basic research system.
- Accelerate the establishment of a national S&T reporting system.
- Implement key national science plans.

135 Tang Yuankai, "Research Funding Overhaul," *Beijing Review*, February 12, 2015, http://www.bjreview.com.cn/nation/txt/2015-02/09/content_668368.htm.

136 "Speech by Xi Jinping at the 17th Conference of the Chinese Academy of Sciences and 12th Conference of the Chinese Academy of Engineering," Xinhua, June 9, 2014.

The abysmal rate of return on S&T investment is a major concern for the Chinese authorities. The country's annual total expenditure on R&D increased by 23 percent on average over the last decade.[137] China invested 1.98 percent of its GDP on R&D between 2006 and 2012, which amounted to RMB 2.42 trillion ($376.3 billion), with more than RMB 1 trillion ($155.5 billion) invested in 2012 alone. This placed China in the second tier of S&T powers alongside the likes of the United Kingdom and Canada, although with a considerable gap to reach the top tier of countries that spend more than 2.5 percent of their GDP on R&D (see Figures 7 and 8). Of the amount that is spent on R&D, the Chinese government invested RMB 1.21 trillion ($188.2 billion) or 11.99 percent of the central budget in S&T efforts.

This increase in funding has been accompanied by a proliferation of funding plans. S&T planning is now done through nearly 40 organizations and nearly 100 funding mechanisms (including the 863, 973, and other plans), with MOST controlling no more than 20 percent of the funding.[138] This patchwork of funding mechanisms has led to redundancy, fragmentation, and inefficiency.[139]

In a perverse way, the large sums of funding allocated to S&T, coupled with lax oversight, has corrupted China's S&T system and created an atmosphere where winning financial support is more important than obtaining research results. The focus on generating income forces top researchers to spend as much as half of their time on business development, resulting in an over-reliance on graduate students to conduct research.[140] The time constraints placed on researchers due to the constant search for funding also leads to researchers to plagiarize or falsify results to get projects done quickly. Researchers also repeat projects, rework existing papers, buy papers, or pay publishers to publish their research output.[141]

Corruption

Corruption has also been a perennial problem. In October 2014, seven professors in five universities were investigated for illegally receiving more than RMB 25 million ($3.9 million) in research funds.[142] In April 2014, Shen Weichen, Party secretary and executive vice president of the China Association for Science and Technology, was placed under investigation for corruption and in December 2014 was kicked out of the Communist Party.[143]

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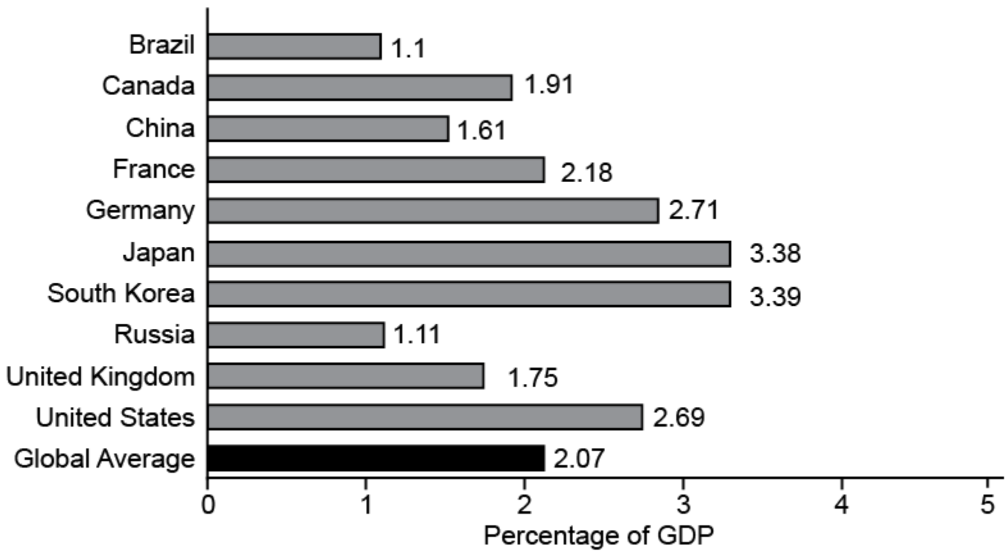
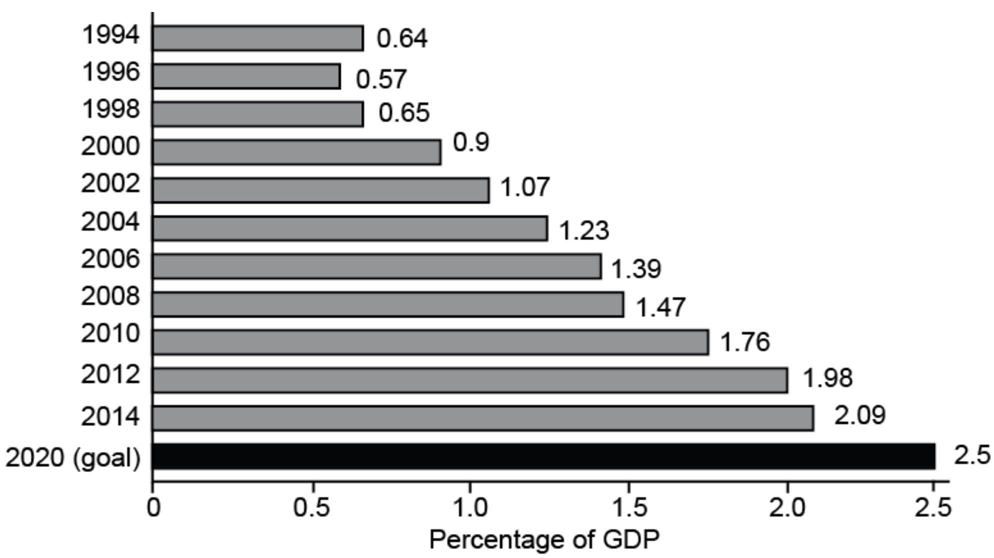
[137] Jane Qiu, "China Goes Back to Basics on Research Funding," Nature.com, March 11, 2014, http://www.nature.com/news/china-goes-back-to-basics-on-research-funding-1.14853.
[138] "MOST Minister Wan Gang Discusses S&T Reform and Development (Transcript)"; "State Council Publishes Notice on Deepening Management Reform."
[139] Ibid.
[140] Tang Yuankai, "Research Funding Overhaul."
[141] Ibid.
[142] Ibid.
[143] "中国科协原党组书记申维辰被双开与他人通奸" [Former Party Secretary of China Association for Science Shen Weizhen Expelled from Party and Position for Adultery], ifeng.com, December 22, 2014, http://news.ifeng.com/a/20141222/42770557_0.shtml.

Figure 7. R&D expenditures as a percentage of GDP for selected countries, 2005–2012 average



Source: Data from World Bank Development Indicators.

Figure 8. China's gross expenditures on R&D as percentage of GDP, 1994–2014



Source: Data from *China Statistical Yearbook on Science and Technology.*

Avenues for corruption are manifold. Research organizations establish multiple front companies which do nothing but serve as funding conduits for the same research. These types of activities are facilitated by overlapping funding mechanisms that are stove-piped and do not coordinate with each other, allowing researchers to fund the same research through multiple sources.[144] Corruption is also exacerbated by the nature of Chinese society with its focus on the importance of relationship building, known as *guanxi*（关系）. Much of the funding and approval process is said to require *guanxi*. As one analyst puts it, “Many individuals and organizations in order to get projects must use *guanxi*. The topic requires *guanxi*. The delivery requires *guanxi*. The evaluation requires *guanxi*.”[145]

Another structural problem is the disparity between the number of people employed in S&T work and the relatively low amount of impactful research generated. There are more than 3.2 million Chinese researchers and scientists, but the overall quality of their scientific output is generally low.[146] A similar situation exists with patents. Although the overall number of patents is high, there is a deficit of core patents and innovative patents.

Exacerbating these systematic flaws is a lack of incentives to promote high-quality research and mechanisms for properly evaluating research. There is also little tolerance of failure and a lack of academic freedom. Many researchers write positive reviews of their own research and pay others to sign them.[147] In other instances, government leaders with little or no science or engineering background determine research topics and evaluate the results.[148] The system for nominating and appointing academicians from the CAS and the CAE is also flawed. Many academicians are nominated to improve the prestige of an organization, and they win appointment through well-financed campaigns.[149] Appointments are also influenced by the substantial benefits given to those who become academicians, with some provinces ranking academicians at the same level as vice ministers.[150]

S&T System Reforms

The critical problems facing China’s STI system have led to a number of broad reforms being introduced in the past few years (Table 4). A key goal of the reforms is to shift the government from a direct hands-on role to a more indirect role in plan management by confining its involvement to the making of general policies, long-range planning, and oversight.[151] Agencies such as MOST will no longer play a decisive role in allocating resources, and they will let the market determine research priorities. MOST’s influence will be limited to providing policy incentives such as tax breaks and beneficial procurement policies. The reform of the S&T system is under the

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[144] Tang Yuankai, “Research Funding Overhaul.”
[145] “Li Naisheng: Several Considerations on Deepening S&T System Reform.”
[146] Sirkin, Zinser, and Rose, “Behind the American Export Surge.”
[147] “Li Naisheng: Several Considerations on Deepening S&T System Reform.”
[148] Ibid.
[149] Ibid.
[150] Jane Qiu, “Chinese Academies Promise Cleaner Elections,” *Nature*, August 10, 2011, http://www.nature.com/news/2011/110810/full/476139a.html.
[151] “State Council Publishes Notice on Deepening Management Reform.”

oversight of the State S&T Organizational System Reform and Innovation System Building Leading Small Group (S&T System Reform LSG)（国家科技体制改革和创新体系建设领导小组）that is headed by Vice Premier and Politburo Standing Committee member Liu Yandong.[152]

The joint council will oversee a number of plan management organizations (PMOs), such as the National Natural Science Foundation of China, and will replace the multitude of agencies that now oversee S&T plans in accepting applications, awarding projects, monitoring work, and evaluating results. These PMOs will be expected to have extensive experience in the management of projects and will be guided by a board of directors, board of supervisors, and a constitution. The PMOs will also rely on a group of vetted expert reviewers selected from a reviewer database to conduct peer review of applications.[153]

Table 4. Reform measures initiated in 2014−2015

Date	Action
March 12, 2014	State Council issues document on science and research plan fund management reform
June 5, 2014	Politburo Standing Committee releases plan on improving the CAS and CAE academician system
Sept. 29, 2014	Central Leading Group for Comprehensively Deepening Reforms considers the Central S&T Finance Plan (Project, Funding) and Management Reform Plan (中央全面深化改革领导小组审议中央财政科技计划（专项、基金等）管理改革方案)
Oct. 27, 2014	Central Leading Group for Comprehensively Deepening Reforms considers the “Opinions on the Opening Up of Major National Basic Science and Engineering Infrastructure and Large Equipment to Society” (中央全面深化改革领导小组审议通过国家重大科研基础设施和大型仪器向社会开放的意见)
Nov.19, 2014	State Council Executive Office issues “Draft Law on Promoting the Transformation of S&T Accomplishments” with a request to the NPC to consider (国务院常务会议讨论通过《促进科技成果转化法》修正案草案，决定提 请全国人大常委会审议)
Dec. 3, 2014	State Council Executive Office releases policy on promoting Zhongguancun as a test bed for S&T reforms
Jan. 12, 2015	State Council Issues “Scheme on Deepening the Reform of the Central Government S&T Plan (Projects, Funds, etc.) Management” (关于深化中央财政科技计划（专项、基金等）管理改革的方案)
March 13, 2015	Central Committee and State Council Issue “State Council Opinions on Deepening System and Organizational Reform and Accelerating the Implementation of an Innovation-Driven Development Strategy” (国务院关于深化体制机制改革加快实施创新驱动发展战略的若干意见)
Sept. 24, 2015	Central Committee and State Council Issue “Implementation Plan for Deepening S&T System Reform” (深化科技体制改革实施方案)

Source: “2014年科技改革发展纪实：创新汇聚中国力量” [An Account of the 2014 S&T Reform Development: Innovation Aggregates Chinese Power], January 8, 2015, http://news.qq.com/a/20150108/025191.htm.

[152] State Council, “国家科技体制改革和创新体系建设领导小组召开会议” [State S&T System Reform and Innovation Building Leading Small Group Convenes Meeting], July 31, 2013, http://www.gov.cn/ldhd/2012-07/31/content_2195192.htm.
[153] “State Council Publishes Notice on Deepening Management Reform.”

A strategic advisory and comprehensive review committee (战略咨询与综合评审委员会）comprised of experts from a cross-section of S&T disciplines, industry, and the economy was created in 2014. This committee will conduct research and advise the joint council on matters related to S&T planning, management, and funding. In order to establish a unified plan evaluation system, a national S&T expert reviewer database will be established, and the committee will provide opinions and advice on standardizing the evaluation of plan management organizations. Under the direction of the joint council, it will pay special attention to large S&T plans. The committee will also work with academic advisory organizations, societies, and associations.[154]

This new system is designed with a "dynamic adjustment mechanism" that is intended to establish a uniform evaluation and monitoring mechanism to ensure that research and funding are properly accounted for. It will also have a publicly accessible national S&T management information system that will provide information on applications for awards, project reporting, funding, and evaluations.[155] In normal practice, projects that have reached the end of their funding cycles will be automatically terminated. In some cases projects will be eligible for continuation beyond their end date, especially if a new S&T plan or key research project has been approved covering the terminated research topic.[156] A "black list" of organizations and researchers ineligible to receive funding will be maintained. Competition for awards will be transparent and managed by a third party.[157] In 2014, the Chinese government launched a national S&T management platform that established a database of central government-financed S&T projects in order to prevent many of the financial abuses discussed above.[158] In some cases, S&T funding regulations have been loosened to allow for activities normally associated with running a research plan. S&T funding will now take into account indirect expenses, administrative activities, incentives for researchers, support for graduate students, and outside consulting.[159]

These structural reforms represent an important initial effort to address some of the most serious deficiencies in the Chinese S&T system. The effectiveness of these reforms will depend on the success of the implementation process. But much more will need to be done to overhaul a management system that has its organizational and normative roots in the Socialist central planning era and that was not designed to manage the huge amounts of funding now being invested in S&T activities.

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[154] Ibid.
[155] "State Council Publishes Notice on Deepening Management Reform"; "《方案》的主要内容" ["Plan's" Main Content], January 14, 2015, MOST website, http://www.most.cn/ztzl/lhzt/lhzt2015/twbblhzt2015/twwm2015/201503/t20150303_118358.htm.
[156] "State Council Publishes Notice on Deepening Management Reform."
[157] Ibid.
[158] "Notice on MOST Beginning 13th FYP National Key R&D Plan."
[159] "Notice on MOST Beginning 13th FYP National Key R&D Plan"; Tang Yuankai, "Research Funding Overhaul."

Establishment of Five New Consolidated S&T Plans and Funds to Replace Existing Specialized S&T Plans

Another major reform underway is the consolidation of the unwieldy number of S&T funding plans into just five plans in order to streamline the path from science to technology to market.[160] This process began in 2014 with six pilot projects.[161]

From 2015 to 2017, existing plans, including the 863 Plan, 973 Plan, the National Science and Technology Infrastructure Plan, and research plans administered by the NDRC and MIIT, will be merged, and funding will be consolidated within these five comprehensive plans (Figure 9). All five will be governed by a unified national S&T management platform to avoid the duplication of funding already discussed. These plans are the:[162]

1. **National Natural Science Fund:** This fund will support basic and cutting-edge research as well as the development of research personnel and teams to strengthen original innovation.
2. **National Major Science and Technology Plan:** This fund will support large-scale strategic projects and major industrialization projects that require coordination at the national level.
3. **National Key R&D Project:** This fund will focus on individual technologies identified as essential to China's S&T and economic development. This includes funding for research on agriculture, energy, life sciences, and health-related S&T projects that will have a long-term impact on society and China's core competiveness, indigenous innovation capabilities, and national security. It will also address basic and long-range scientific questions, critical technologies and products, and large-scale international cooperation. Another goal is to strengthen inter-departmental, inter-industrial, and cross-regional R&D efforts through coordinated innovation.
4. **Special Fund for Technology Innovation:** This fund will streamline funding activities by consolidating various funding plans supervised by the NDRC, MOF, MOST, MIIT, and MOFCOM. It will encourage the use of private capital and financial capital to foster technology innovation and will create government-guided angel investing, venture capital, and risk compensation mechanisms. In addition, the government will use indirect measures to support innovation and improve tax incentives and government purchasing policies to promote innovation.
5. **R&D Base and Professional Special Plan:** This plan will improve and support the development of research facilities and human resources. It will merge MOST-managed state key laboratories, state engineering research and technology centers, S&T infrastructure platforms, and the Creative Talents Promotion Plan, as well as NDRC-managed state engineering laboratories, state engineering research centers, and state certified enterprise technology centers. It will also improve and better link talent development plans.[163]

[160] "Plan's Main Content."
[161] "MOST Minister Wan Gang Discusses S&T Reform and Development (Transcript)."
[162] "Notice on MOST Beginning 13th FYP National Key R&D Plan"; Tang Yuankai, "Research Funding Overhaul."
[163] "《关于深化中央财政科技计划（专项、基金等）管理改革的方案》政策解读" [Policy Explanation on Deepening the Management Reform Central Funding of S&T Plans (Items and Funds)], January 1, 2015, Ministry of Science and Technology website, http://www.most.cn/kjzc/zdkjzcjd/201501/t20150106_117286.htm.

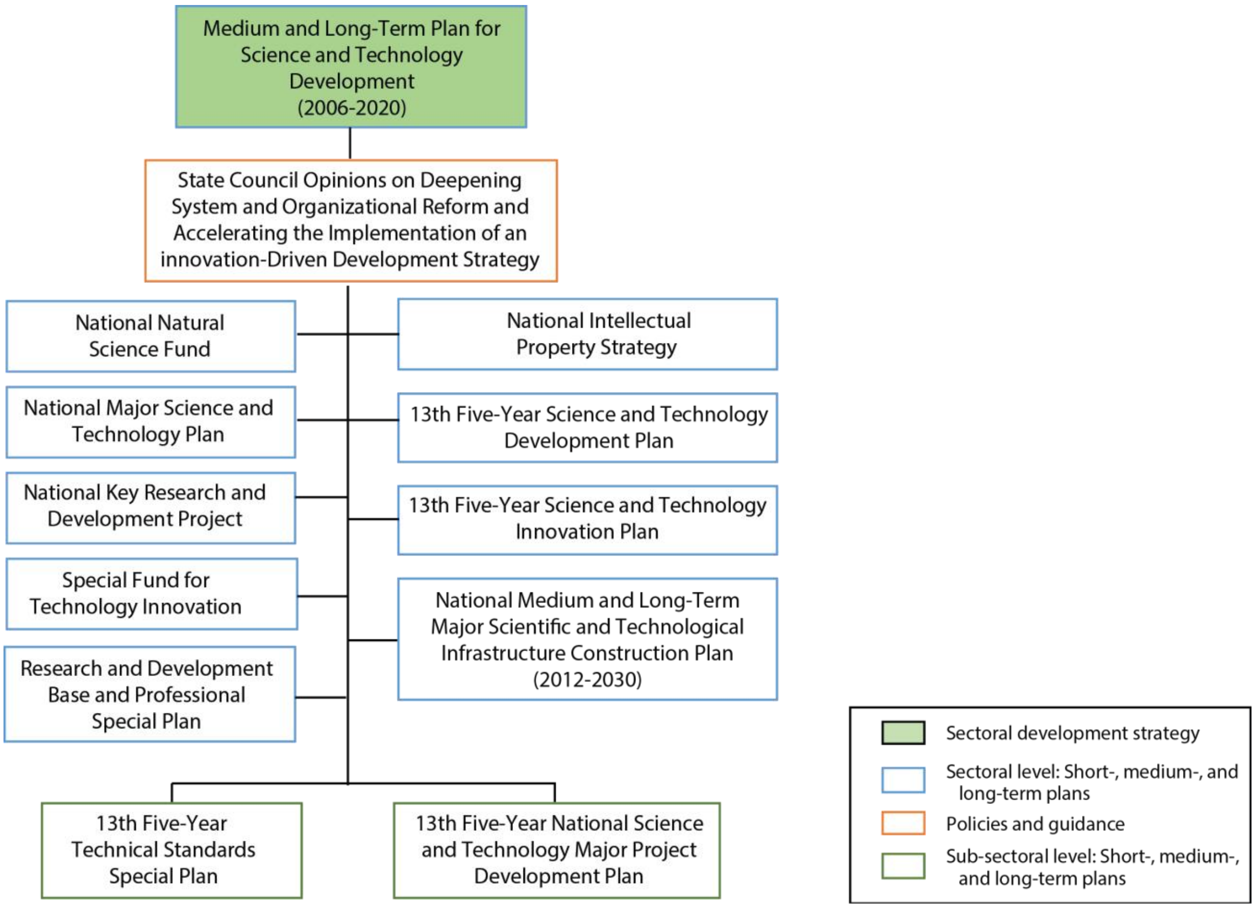

Figure 9. China's state strategies and plans for science and technology development (post 2017)

The National Key R&D Plan (NKRDP) is by far the largest and most important of these five new categories and was officially established in February 2016. The plan is designed to be as broad and inclusive as possible, supporting R&D in areas such as agriculture, healthcare, energy, environment, industrial competitiveness, innovation, and national security.[164] Unlike the legacy programs that the NKRDP replaces that were divided according to where they were on the R&D spectrum (from basic research to engineering development), the new plan covers all the phases of the research, development, and production cycle with the goal of improving commercialization rates.[165]

Existing S&T programs that have been subsumed into the NKRDP include the 863 Plan, 973 Plan, National S&T Support Program (国家科技支撑计划), and International S&T Cooperation and Exchange Project (国际科技合作与交流专项). In addition, industrial technology research and development funds managed by NDRC and MIIT, and not-for-profit industrial research projects

164 Ibid.
165 Ibid.

managed by other government agencies have also been placed under the jurisdiction of the NKRDP.[166]

At the outset, the NKRDP has taken over responsibility of 59 existing key projects (重点专项) as well as another 36 brand-new projects that have been recommended for research funding by the State S&T System Reform and Innovation System Construction Leading Group (国家科技体制改革和创新体系建设领导小组) that was then ratified by the State Council.[167] The leading group listened to specialist advice that was provided by more than 900 high-level outside experts along with input from government agencies. MOST, MOF, and NDRC also were involved in the review process by assessing recommendations and picking those that would best fit with current national development strategies such as Made in China 2025, the Internet Plus plan, "One Belt, One Road," and the Energy Development Strategy Action Plan. Other considerations in project selection included making sure that there was a healthy balance across different priority industrial sectors, such as agriculture, energy resources, ecology/environment, and health.[168]

Nine projects were unveiled at the same time as the NKRDP was announced:[169]

1. Nanotechnology
2. Quantum control and quantum information
3. Big science equipment frontier research
4. Protein machines and life process regulation
5. Food production efficiency
6. Modern food processing, storage, and transportation technology and equipment
7. Major animal epidemic prevention and control and efficient and safe breeding technology
8. Forest resource cultivation
9. Smart agricultural machinery and equipment

[166] "973, 863 计划取消 国家重点研发计划启动" [973 and 863 Programs Cancelled; National Key R&D Plan Officially Launched], *Xinhua News Agency*, February 16, 2016, http://news.sciencenet.cn/htmlnews/2016/2/338353.shtm.
[167] The leading group was established in 2012 and is headed by Liu Yandong, the senior party leader in charge of the S&T portfolio. See 国家科技体制改革和创新体系建设领导小组召开第一次会议 刘延东主持并讲话 [State S&T System Reform and Innovation System Construction Leading Group Opens its First Meeting, Liu Yandong Presides and Speak], Xinhua, July 30, 2012, http://news.xinhuanet.com/politics/2012-07/30/c_112574602.htm.
[168] "科技部副部长侯建国谈国家重点研发计划启动" [MOST Vice Minister Hou Jianguo Discusses Launch of National Key R&D Plan], 科技日报 [*S&T Daily*], February 17, 2016, http://news.sciencenet.cn/htmlnews/2016/2/338356.shtm.
[169] "科技部关于发布国家重点研发计划纳米科技等重点专项 2016 年度项目申报指南的通知" [MOST Notice Regarding Release of National Key R&D Plan Nanotechnology, etc. Key Projects, 2016 Programs Application Guide], Ministry of Science and Technology, Doc. No. 36, February 16, 2016, http://www.most.gov.cn/kjjh/xmsb/sbzj/201602/t20160215_124109.htm.

In December 2015, MOST had provided details of application guidelines of six pilot research projects that would be included in the NKRDP:[170]

1. Stem cells and transformation
2. Digital medical equipment
3. Air pollution causes and control technology
4. New energy vehicles
5. Chemical fertilizers and pesticide reduction and efficiency technology
6. Seven types of major crop breeding

The project selection process for the NKRDP is still in a transitionary stage and the end goal is for MOST, MOF, and the NDRC to take the lead. They, along with another 31 government agencies, will establish an independent interministerial-level decision-making body to pick future projects. One senior Chinese S&T advisor said that there was so far little consensus among these agencies as to the final design for this entity.[171] The other four remaining programs are expected to be launched by the end of 2016, although full-scale implementation is not scheduled for completion until 2019.[172]

[170] "科技部关于发布国家重点研发计划试点专项 2016 年度第一批项目申报指南的通知" [MOST Notice Regarding Release of National Key R&D Plan Pilot Projects, 2016 First Project Set Application Guidelines], Ministry of Science and Technology, Doc. No. 384, December 14, 2015, http://program.most.gov.cn/htmledit/BD000AFF-9047-59BC-D7BE-ACFA174F48BF.html.
[171] Interview, San Diego, February 2016.
[172] Hou Jianguo stated that the set of S&T reforms outlined in Doc. No. 64 would be completed in three years. *S&T Daily*, February 17, 2016.

ENERGY IN CHINA

Energy planning is a core function of the Chinese party-state, and it retains a tight grip not only through the government administrative apparatus but also within state-owned energy-related enterprises that are led by high-ranking party members. Energy is essential to every aspect of an economy, and China's history leaves its government concerned that neglect might lead to shortages. The oil and gas sector, the grid companies, the power generating companies, most coal mining operations, and the majority of power generation equipment manufacturing in China are state-run. The Chinese government has opened up select energy subsectors to private enterprises, especially in new technology areas such as solar and wind energy, and encouraged cooperation with international companies ranging from licensing to joint ventures in areas where it has sought outside technology (such as renewables, nuclear power, and offshore oil production). The overarching concern, however, has been to maintain domestic control of what is viewed as a strategic lifeline of the Chinese economy.

This interest in domestic state ownership is informed by a strong concern over scarcity and of vulnerability. These worries stem from the CCP's history, in particular the Sino-Soviet split of 1960, which led to Soviet restrictions and ultimately the curtailment of oil sales to China.[173] Although energy supplies can be fungible in the long run, they are not easily substitutable in the short term because of the heavy investment needed in source-specific infrastructure. Moreover, transportation relies heavily on the supply of liquid fuels. At the beginning of the 1960s, the fledgling Chinese economy found itself seriously imperiled.[174] China's great stroke of fortune was the discovery of the vast Daqing oilfield in 1959, which quickly went into full-scale production in 1961.[175] Daqing and, to some extent, a few smaller fields in northeast China provided the country with thirty years of energy independence. Since 1993, however, China has become a net oil importer due to rising domestic demand and the falling output from Daqing's oilfield.[176]

The analysis of the Chinese energy landscape proceeds as follows. It begins with a brief description of the major plans. A discussion of the drivers of China's energy policy, and of conservation and diversity of supply, two major themes in the planning documents, follows this introduction. The discussion then goes into detail on the 12th FYP, and Table 5 (pp. 74–75) provides specifics on Chinese progress toward meeting its current FYP goals.

The Chinese energy system is then described, first the government structure and its policymaking bodies and then how the major industries themselves are organized. This is followed by an examination of how the Chinese government sees these plans in a global context. The analysis then

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[173] Monique Taylor, *The Chinese State, Oil, and Energy Security* (New York: Palgrave Macmillan, 2014).

[174] The Great Leap Forward (1958–1960) was Chairman Mao's attempt to leap directly to a communist future, bypassing a Soviet model of development that he saw as slow. It involved the creation of backyard steel mills and other attempts at local industrialization, and the collectivization of agriculture. The result was a crash in agricultural productivity and the largest famine in human history, with death estimates ranging from 20–45 million. Frank Dikötter, "Mao's Great Leap to Famine," *New York Times*, December 15, 2010, http://www.nytimes.com/2010/12/16/opinion/16iht-eddikotter16.html; "Mao and the Great Leap Forward," researched by Edwin Daniel Jacob, Center for the Study of Genocide and Human Rights, Rutgers University, accessed June 24, 2016, http://www.ncas.rutgers.edu/mao-and-great-leap-forward.

[175] "History of Daqing Oilfield," Daqing Oilfield website, accessed October 15, 2015, http://dqyt.cnpc.com.cn/dqen/HoDO/dqen_common.shtml.

[176] Erica S. Downs, "The Chinese Energy Security Debate," *China Quarterly* 177 (2004): 21–41.

moves to two critical areas for energy planning, demand and technology (since the interest in indigenous innovation is important to energy planners). Finally, two major policy issues for the sector, market reform and environmental protection, are considered.

China's Energy Plans

Energy is a key element of the five-year planning process, and the overall People's Republic of China Five-Year Economic and Social Development Plan provides the essential targets and guidance for this critical sector. Greater detail is provided in sectoral and provincial FYPs.

The specific technology and quantity targets (detailed in the discussions of each industry) are contained in the sectoral plans (Figure 10). These include plans for the coal, oil and gas, and power sectors, and a large number of subsectoral plans for nuclear energy, renewable energy, smart grid, and natural gas development. Within the renewables category, there are also specific plans for solar, wind, hydro development, and technology.

Besides the specific energy plans, there are critical environmental plans that affect these sectors, since most pollution ultimately arises from the burning of fossil fuels. These key plans include those for: 1) environmental protection, covering all the major pollutants that affect human and ecosystem health, mainly SO_2, NOx and particulates); 2) energy efficiency, including subsectoral plans for industrial energy efficiency; and 3) climate change, which relies on energy efficiency plans, as well as nuclear and renewable energy development, for all of its gains.

The provincial plans are also important, especially as they pertain to energy efficiency and environmental targets. These targets are allocated to each province, who then allocates targets to cities and counties.

The Chinese authorities also try to plan for critical resources beyond the five-year planning cycles. The longest commitments in these plans are embodied in the climate planning process, where the Chinese government has committed to the UN Framework Convention on Climate Change to "peaking carbon dioxide emissions around 2030 and making best efforts to peak early," and reducing the carbon intensity of the economy (carbon dioxide per unit GDP) by 60 to 65 percent by 2030 from a 2005 baseline.[177]

This follows through from China's 2014–2020 Climate Change Action Plan, which calls for implementing nuclear, renewable, and energy efficiency plans.[178] It also calls for restructuring the Chinese economy away from energy-intensive industries and toward both greater value-added sectors and the service sector, which is also an overall 13th FYP goal. Moreover, the plan provides a roadmap for developing carbon trading. This began with pilot projects and is now being developed into a nationwide carbon-trading system. These climate targets reflect both what needs to be achieved in these areas, and what Chinese planners actually believe they can achieve, since they are based on years of modeling.[179]

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[177] "Enhanced Actions on Climate Change," submitted by the government of China to the UN Framework Convention on Climate Change on June 30, 2015.
[178] "国家应对气候变化规划(2014–2020 年)" [China National Climate Change Plan (2014–2020)], 2014.
[179] A literature survey of the major modeling exercises in the public domain is provided in Warwick J. McKibbin et al., "China's Carbon Future: A Model-Based Analysis," Brookings Institution, December 31, 2015.

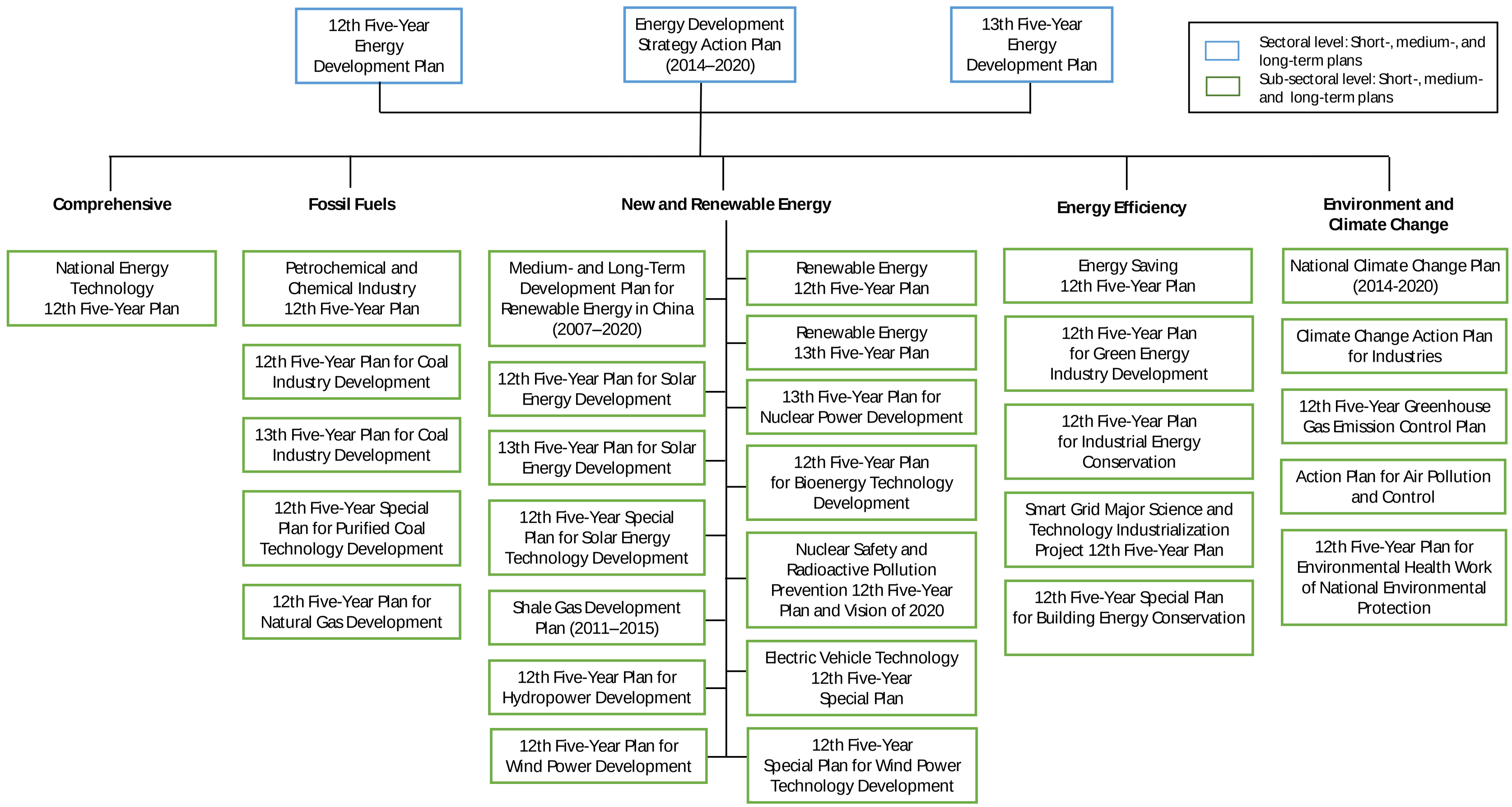

Figure 10. China's state strategies and plans for energy development

Another planning document is the 2007 Medium- and Long-Term Plan for Renewable Energy. The overall thrust of this plan, which is still underway, is the importance of implementing the Renewable Energy Law, which includes provisions for increasing the production of renewable energy and for connection to the state grids. The specific targets of this plan have been subject to extensive modification, and the 2020 targets for solar, wind, and hydropower have already been surpassed. For example, the wind target of 30 gigawatt (GW) was surpassed before the 12th FYP began in 2011. The solar target of 1.8 GW was met in the 12th FYP's first year, and the hydro target of 300 GW in 2014.

Subsequent plans have given higher targets. Given the rate of growth, especially in both wind and solar, the 13th FYP targets issued in March 2016 will be instructive. The 2007 plan does provide capacity estimates that may be more relevant, with exploitable hydro resources estimated to be 540 GW, while economically feasible hydro is at 400 GW, suggesting that China will soon complete its hydro build-out. Feasible wind potential was estimated at 300 GW onshore, and a total of 1000 GW on and offshore. Solar potential was not given in GW, but the plan suggests large potential, with two-thirds of China's territory receiving more than 2,200 hours of sunshine annually.[180]

Climate planning contributes directly to the type and direction of energy development, as it relies on the implementation of energy efficiency and non-fossil energy plans. The impact of air pollution planning is even more complex: 1) it constrains fossil fuel growth in order to meet targets; 2) it affects the fossil fuel mix, since coal is more polluting than natural gas; and 3) it can affect the size and type of industries, since small-scale industry is difficult to regulate and often easier to simply shut down.[181] The key targets are both in the national FYP as well as in the Air Pollution Action Plan of 2013, which gives strict 2017 targets for three major regions: the Beijing-Tianjin airshed, the lower Yangtze River airshed, and the Pearl River airshed.

The Overriding Determinants of Chinese Energy Policy

China's sense of vulnerability to external cut-off, combined with the real experience of scarcity in oil supply (as well as electric power, where supply was often unable to keep up with demand), informs China's energy policy to this day. While there is no longer a realistic way for China to be independent in oil and gas, nor in nuclear power since its uranium supplies are imported, the emphasis on independence is now often linked to technology concerns. Traditionally, 'energy independence' was synonymous with 'energy security,' and generally referred to security of supply. Today these concepts are more encompassing. While Chinese are still first concerned with the international supply of fuels, equally important is concern for control of technology, in other words patents and licenses without fees.

Energy security also encompasses domestic concerns such as potential supply risks, including weather or transport disruptions. Fuel supply security is also a major concern motivating the plans related to energy efficiency and conservation listed earlier. Diversification to address the international and domestic risks to energy security are clearly addressed in the Medium- and Long-term

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[180] See "Medium and Long-Term Development Plan for Renewable Energy in China," September 2007, http://www.martinot.info/China_RE_Plan_to_2020_Sep-2007.pdf, for a useful English language summary of the plan.

[181] Jessica Mary Yu, "Blue Skies Over Beijing? Decaying Suburbs Bear Cost as China Cuts Pollution," Reuters, January 26, 2016.

Development Plan for Renewable Energy in China (2007–2020), and the multiple separate plans for wind, solar, and hydropower; for new fossil fuel sources, particularly shale oil and gas; and for nuclear power.

In the examination of the multitude of five-year, medium- and long-term, comprehensive and sector-specific energy development plans, three major approaches emerge. The first is an emphasis on **conservation**. Conservation is a core value in the overall FYPs, as well as the 12th Energy Development Five-Year Plan; the various sub-plans on energy efficiency, industrial energy efficiency vehicles, and smart grids; and those related to climate change, including the National Climate Change Plan (2014–2020) and China's Policies and Actions on Climate Change (2015). While there have been times, particularly in the early 2000s, where an emphasis on supply growth superseded a policy focus on conservation and efficiency, current efficiency efforts beginning with the 11th FYP in 2006 build on a legacy that extended from 1949 through the late 1990s.

China's efforts to conserve energy and use it more efficiently clearly complement US and many other countries' interests in reducing carbon emissions and dependence on fossil fuels. To this end, the Chinese effort to increase the efficiency of its coal-fired power plants and to develop more modern and cleaner (and potentially carbon-capture ready) technologies contributes both to its own efforts to reduce carbon and air pollution and to that of other developing countries, which are often its customers for new power plants.

China's second strategic response to vulnerability and its lack of true energy independence is to emphasize **diversity of supply**. This diversification applies not only to seeking imported fuel from multiple sources, but also to an active effort to develop alternative energy supplies. China today has the largest installed hydroelectric power capacity, and unlike many other major hydro producers, like the United States, Canada, and Norway, it continues to have an active dam-building plan.[182] It also has by far the most active nuclear power development plan in the world, and it is installing wind and solar power projects at a rapid rate.

While these efforts support global climate change and energy security goals, at the same time Chinese energy planning documents express the view that the energy system is inherently competitive, embodying a sense of potential conflict with the United States and other countries. The 12th Five-Year Energy Plan lists five major international concerns:

1. *Increasing international competition for resources.* Chinese policymakers are concerned that there are ever more rapidly growing countries in need of energy. They do not see an abatement in the international political and economic pressure for energy resources, particularly for oil.

[182] "3.1 Current Hydropower Capacity and Generation," in "Renewable Energy Technologies: Cost Analysis Series—Hydropower, International Renewable Energy Agency (IRENA)," June 2012, http://cleanleap.com/3-global-hydropower-capacity-and-generation-trends/31-current-hydropower-capacity-and-generation.

2. *Rapidly changing supply and demand.* As new sources open up in such places as West Africa and the United States (exemplified by the shale revolution), other countries' demand also rapidly changes, such as Japan's increase in oil demand in the post-Fukushima era, as it closed down its nuclear power plants.[183]
3. *Price volatility.* The rapid increase and then equally rapid fall in global oil prices has been difficult for Chinese energy planners to manage. China operates with state-set prices at the consumer level for both liquid fuels and electricity, but it has tried very hard to align these prices with the international market. Shifting oil and gas prices have made this type of planning difficult. It also makes investment decisions extremely challenging.
4. *Climate change.* Concerns here are centered on international pressure, both in terms of China's emissions rights (how much of total world emissions China would be entitled to in an agreement) and the potential that other countries would use trade barriers to enforce their view of China's emissions entitlements. This is in addition to domestic concerns about environmental protection and the need to limit the environmental damage caused by energy use.
5. *Competition for leading innovative technologies.* The plan specifically cites the competition for new clean technologies and suggests competition in areas including energy conservation, low-carbon development, energy storage, and energy-related IT. It repeatedly states the need for Chinese ownership of IP and seeks to foster "indigenous innovation."

Indeed, in each of the separate energy technology plans, the third strategic focus, **indigenous innovation**, is a top priority. The stated desire is to localize all technological aspects of the energy supply chain. However, as will be discussed in further detail, not all of these efforts have the same government and corporate interests behind them. While China has made tremendous progress in localizing power generation technology, for example, it is much further behind in oil and gas development technologies. Many of these gaps appear unlikely to be bridged in the near future.

Although Chinese domestic priorities offer complementarities for international cooperation such as with their efforts to conserve and diversify sources, concern for environmental protection, and prudent use, their views of the international environment also suggest a strong competitive impetus that entails risks for other countries, including the United States.

The 12th Energy Development Five-Year Plan: Goals and Progress

China's 12th Five-Year Plan set a number of key goals for energy consumption and environmental protection under the overall notion of "energy efficiency and pollution abatement" and in accordance with China's international climate commitments. Key targets included reducing energy intensity by 16 percent, carbon intensity by 17 percent, and key air pollutants by 8 percent. There were also specific targets for each energy source, as detailed in Table 5.

[183] According to McKinsey Solutions, the share of electricity generated from fossil fuels increased in Japan from 63 to 87 percent between 2011 and 2013, and oil consumption in power plants witnessed a sharp increase from 2011 to 2014. Tanay Vora and Sharad Saxena, "Japan's Uncertain Energy Future in the Post-Fukushima Era," McKinsey Energy Insights, January 2015, https://www.mckinseyenergyinsights.com/insights/japan%E2%80%99s-uncertain-energy-future-in-the-post-fukushima-era.aspx.

Table 5. Energy plan goals and achievements

	Goals as stated in 12th FYP				Status			
Indicator (units)	2010	2015 goal	Expected annual growth rate	Expected 5-year cumulative growth rate	**2015**	Actual CAGR	Actual 5-year cumulative growth rate	**2020 goal[1]**
Energy consumption and efficiency								
Total primary energy consumption (MTCE)	3,250	4,000	4.3%	23.1%	4,300[2]	5.8%	32.3%	4,800
Total electricity consumption (TWh)	4,200	6,150	8.0%	46.4%	5,550[3]	5.7%	32.1%	
Energy intensity (energy consumption per unit of GDP) (tce/RMB 10,000)	0.81	0.68		(–16%)	0.662[2]		–18.2	
Thermal power coal consumption (gce/kWh)	333	323	–0.6%	–3.1%	315[3]	–1.1%	–5.4%	~300
Power line loss rate	6.5%	6.3%		(–0.2%)	6.6%[3]		1.5%	
Energy production and supply								
Domestic primary energy production (MTCE)	2,970	3,660	4.3%	23.2%	3,620[2]	4.0%	21.9%	4,200
Coal production (MTCE)	3,240	4,100	4.8%	26.5%	3,695[4]	2.7%	14.0%	
Crude oil production (Mt)	200	200	0	0	214.6[2]	1.4%	7.3%	
Natural gas production (bcm)	94.8	156.5	10.5%	65.1%	134.6[2]	7.3%	42.0%	
Non fossil energy production (MTCE)	280	470	10.9%	67.9%	N/A	N/A	N/A	
Electricity development								
Electricity capacity (GW)	970	1,490	9.0%	53.6%	1,507[3]	9.2%	55.4%	
Coal-fired power (GW)	660	960	7.8%	45.5%	990.2[3]	8.5%	50.0%	
Hydropower (GW)	220	290	5.7%	31.8%	319.4[3]	7.7%	45.2%	350
Nuclear power (GW)	10.8	40	29.9%	270.3%	26.08[3]	19.3%	141.5%	58
Natural gas-fired power (GW)[7]	26.4	56	16.2%	112.1%	N/A	N/A	N/A	
Wind power (GW)	31	100	26.4%	222.6%	129.3[2]	33.6%	317.1%	200
Solar power (GW)	0.86	21	89.5%	2,341.9%	43.2[2]	118.9%	4,923.3%	100
Environmental protection								
Carbon intensity (carbon emission per unit of GDP)			(–17%) 2010 baseline			N/A	–20%[5] 2010 baseline	40–45% 2015 baseline
Coal-fired power sulfur dioxide emissions (g/kWh)	2.9	1.5	–12.4%	–48.3%	N/A	N/A		

Table 5. Energy plan goals and achievements (continued)

	Goals as stated in 12th FYP				Status			
Indicator (units)	2010	2015 goal	Expected annual growth rate	Expected 5-year cumulative growth rate	**2015**	Actual CAGR	Actual 5-year cumulative growth rate	**2020 goal**[1]
Environmental protection (continued)								
Coal-fired power nitrogen oxide emissions (g/kWh)	3.4	1.5	–15.1%	–55.9%	N/A	N/A	N/A	
Livelihood Improvement								
Per capita residential electricity consumption (kWh)	380	620	10.3%	63.2%	531.1[6]	6.9%	35.0%	
Green energy demonstration counties	108	200	13.1%	85.2%				
Population using natural gas	180 million	250 million	6.8%	38.9%				

Notes: The expected annual growth rate (col 4) is calculated as Compound Annual Growth Rate (CAGR), which is equal to (2015 Goal/2010 Actual)$^{(1/year)}$ – 1. Actual CAGR (col 7) is equal to (2015 Actual)/2010 Actual)$^{(1/year)}$ – 1. All numbers in parentheses are government target listed in the 12th FYP. MCTE = million tonnes of coal equivalent; TWh = terawatt hour; tce = tonne of coal equivalent; gce = gram of coal equivalent; Mt = million tons; and bcm = billion cubic meters.

Sources:
1. "国务院办公厅关于印发能源发展战略行动计划（2014–2020 年）的通知" [Action Plan on Energy Development Strategy (2014–2020)], The State Council website, November 19, 2014, http://www.gov.cn/zhengce/content/2014-11/19/content_9222.htm.
2. "2015 年国民经济和社会发展统计公报"[2015 National Economy and Social Development Statistics], National Bureau of Statistics website, February 29, 2016, http://www.stats.gov.cn/tjsj/zxfb/201602/t20160229_1323991.html.
3. "国家能源局发布 2015 年全社会用电量" [National Energy Administration Released 2015 Total Energy Consumption Statistics], National Energy Administration, January 15, 2016, http://www.nea.gov.cn/2016-01/15/c_135013789.htm.
4. "煤炭行业每日资讯:2015 年全国原煤产量 36.95 亿吨" [Coal Industry Daily News: The Production of Coal in 2015 is 3.695 Billion Tons], January 20, 2016, http://finance.qq.com/a/20160120/035257.htm.
5. ""十二五"应对气候变化工作成果丰硕" [Great Achievements in Addressing Climate Changes during "12th Five-Year"], National Development and Reform Commission, February 23, 2016, http://zys.ndrc.gov.cn/xwfb/201602/t20160223_775157.html.
6. Total household electricity consumption is 727.6 billion in 2015 ("National Energy Administration Released 2015 Total Energy Consumption Statistics") and the 2015 population is 1.37 billion ("2015 National Economy and Social Development Statistics").

According to the Midterm Evaluation Report of China's 12th FYP in 2013, China was behind schedule in meeting targets for the first two years. Progress lagged on four energy and environment-related binding targets, which are for energy intensity, carbon dioxide emissions, rationalization of energy consumption, and nitrogen oxide emissions. By 2014 China had moved more rapidly and ultimately exceeded goals in all these hard targets, and by 2015 they had achieved significantly more than the targets in all these areas.

The uneven progress—in particular slow progress on some goals for the first two years and then rapid catch-up—is fairly typical of Chinese local government response to five-year plans. Similar progress was demonstrated on the energy intensity goal in the 11th FYP, with escalating compliance in the later years. This is particularly striking for NOx emissions, where the implementing regulations for power plants, a major source and the main change in control in this FYP cycle, did not come into effect until July 2014. Thus, most of the build-out of abatement equipment did not begin until 2012.[184] The clear exception to this pattern of rapid catch-up is natural gas production, where it appears unlikely to meet its 156.5 billion cubic meters (bcm) target. The issues with natural gas are detailed in the demand and technology sections that follow.

The Structure and Process of Chinese Energy System

China's great energy needs are supplied for the most part by state-owned enterprises operating under the supervision of the central government. While the CCP sets overall policy, its instructions tend to be broad and simply set general direction and guidance. These goals are on the order of increasing and diversifying the energy supply, developing new technologies, controlling costs, and mitigating pollution. Government agencies are responsible for the technical work of setting specific long-term targets and choosing specific plans as well as day-to-day policy work. One example is the role of the Leading Group (领导小组) coordination structure for China's energy industry. While some leading groups, such as foreign affairs, are run by the CCP, the previous Leading Group for National Energy Resources (国家能源领导小组) and its post-2010 successor, the National Energy Commission, are under the State Council. This is also true for the other two leading groups relevant to energy policy: the Leading Group for Science, Technology, and Education (国家科技教育领导小组) and the Leading Group for Environmental Protection (国务院环境保护领导小组).[185]

China no longer has an energy ministry, which it did at certain times in the past. It also no longer has specific ministries for coal, oil, or other energy sources. All of these ministries were turned into SOEs in the 1980s. The result is a complex structure overseen by the National Energy Commission (Box 2) as well as directly by the State Council, with multiple ministries playing important roles (Box 3). Traditionally, the energy sector has had more autonomy than other sectors, and its companies could pursue their own plans. During the mid-2000s, when oil prices were high, energy policy became a much higher central government concern, with the premier and the head of the NDRC rather than one vice premier and one vice chairman directly involved. Today, with oil prices lower, central government focus has lessened, but at the same time a series of corruption scandals, particularly those that have damaged the petroleum sector, have reduced the energy sector's ability to act independently. The result is much greater caution, particularly in the oil and gas sector.

Moreover, the heads of the major SOEs are high-ranking party members, in some cases more senior than ministers, and consequently are often able to operate with a considerable degree of autonomy.[186] This independence is enhanced and coordination impaired by the complex set of agencies with differing degrees of power and influence in the energy sector. Nevertheless, the high level of the NEC itself speaks to the overall importance of energy in national policy.

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[184] Author interviews in Beijing, November 2015.
[185] Alice Miller, "The CCP Central Committee's Leading Small Groups," *China Leadership Monitor* 26 (2008): 1–21.
[186] For instance, Sinopec CEO Wang Yupu is a member of the CCP Standing Committee, while Environment Minister Chen Jining is not. This discrepancy was even greater before the oil industry lost standing in the anti-corruption campaign.

Box 2: The National Energy Commission

The National Energy Commission was established in 2010 to replace the Leading Group for National Energy Resources. Coordinating bodies exist at different levels of government.

The fact that the NEC is chaired by the Premier shows that it is a very high-level coordinating body and one that can actually expect responses from the ministries under its purview.

The key indicator for where power lies is in the structure of its secretariat, which is headed by the director of the NDRC, with the National Energy Administration (NEA) director serving as vice director.

While both the NDRC and the NEA have policy responsibility, the NDRC ranks above the NEA. Placing day-to-day coordination of energy policy in the hands of the NDRC, which is one of China's most powerful ministries, gives the NEC secretariat significant authority.

The members of the NEC are all at the ministerial level and are from nearly 20 state, financial, and national security organizations:

State Council
Leading Group on Financial and Economic Affairs
Ministry of Foreign Affairs
National Development and Reform Commission
Ministry of Science and Technology
Ministry of Industry and Information Technology
Ministry of State Security
Ministry of Finance
Ministry of Land and Natural Resources
Ministry of Environmental Protection
Ministry of Transport
Ministry of Water Resources
Ministry of Commerce
People's Bank of China
State-owned Assets Supervision and Administration Commission (SASAC)
State Administration of Taxation
State Administration of Work Safety
China Banking Regulatory Commission
People's Liberation Army General Staff Department

Sources: "Government Structure and Ownership: Nuclear Power in China Appendix 1," World Nuclear Association website, updated September 2015, http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Appendices/Nuclear-Power-in-China-Appendix-1--Government-Structure-and-Ownership/; "Li Keqiang Takes the Post of National Energy Commission Chairman," China Council for International Cooperation on Environment and Development website, July 23, 2013, http://www.cciced.net/encciced/newscenter/latest-news/201307/t20130723_256063.html.

Box 3: Ministerial Supervision

The main ministries and commissions that have major roles in the daily implementation of energy policy and long-term planning are as follows:

National Development and Reform Commission (NDRC): Sets overall energy policy, including climate change policy, and supervises permitting of new projects. It also supervises the National Energy Administration, which is a subministerial body.

National Energy Administration (NEA): Carries out much of the day-to-day work of administering energy policy and issuing project permits. This includes recommending standards, priorities, and plans to the NDRC. In 2013, the NEA absorbed the State Electricity Regulatory Commission, giving it specific regulatory authority over the power market, as well as responsibility for power safety and reliability.

Ministry of Water Resources (MWR): Regulates the hydropower industry and also plays a key role in setting water use policy for thermal and nuclear power plants. Many new thermal power plants in China are air-cooled, and nuclear power plants are located near the coast, where they can use seawater.

Ministry of Land and Resources (MLR): Administers all land use permits. This covers mining, drilling and facility construction.

Ministry of Science and Technology (MOST): Sets policy and provides funding for R&D in advanced technologies.

Ministry of Industry and Information Technology (MIIT): MIIT has some policy involvement in all SOEs, but its involvement in the energy sector concerns non-fossil energy. It houses the China Atomic Energy Agency (CAEA), the regulator for nuclear planning (not safety, which is under the Ministry of Environmental Protection). CAEA is under SASTIND, which oversees the country's industry and the emerging civil-military dual-use sector. Nuclear-related development continues to be closely connected with the defense establishment despite being housed under a civilian ministry. MIIT is also involved in both standard and target-setting, particularly for the wind and solar sectors.

Ministry of Environmental Protection (MEP): Regulates the environmental impact of energy through three key functions: 1) Sets pollution standards for all pollutants except greenhouse gases, 2) Evaluates Environmental Impact Assessments at the project approval stage; and 3) Administers comprehensive pollution monitoring and enforcement at the operations stage. It also houses the National Nuclear Safety Administration, the country's nuclear safety regulatory body.

State-owned Assets Supervision and Administration Commission (SASAC): SASAC governs the largest state-owned enterprises in China (currently 112 entities). Fifteen of these SOEs are major energy producers and another seven are major equipment manufacturers or service providers. In some areas, such as oil and gas, the electric grid, and nuclear manufacturing and generation, SASAC-controlled companies enjoy monopoly control over the entire sector. In others, such as power generation equipment they represent a clear majority. In power generation and coal production, SASAC controls a minority of the sector. Heads of SASAC-controlled companies are appointed either by the CCP's Central Organization Department or by SASAC itself. SASAC's main function is to ensure these firms pay dividends to the government. In other words, SASAC acts as the firms' owner and as such enjoys considerable power.

Energy Policymaking and Planning

Energy policymaking is centered in the NDRC and NEA. For most purposes, NEA acts as a bureau of the NDRC, and their major function is planning. NDRC is the heir to the old State Planning Commission and continues to have a number of planning functions, particularly in relationship to the key industries under the FYPs, of which energy is one.[187] The planning functions include production and consumption targets for all major fuels, investments in new technologies, and the designation of both priority projects and priority localities. The planning process states not only which technologies will be emphasized but also where such development should take place. NDRC and NEA also issue permits for all major projects and thus act as the gatekeeper and final arbiter for most major energy investment decisions.

Projects may originate with either companies or governments. Project approvals are then made at different levels of the state bureaucracy. The approval level is determined by the type of industry and the size of the investment. The central authorities only become involved with large-scale projects, as defined by investment size, but this threshold varies by industry. As a result, small-scale projects often wind up under the national government's radar. For example, many small-scale fossil fuel (often diesel or fuel oil) power plants were built along China's east coast, especially during years when there were energy shortages. Numerous small-scale coal mines were also opened. However, these small-scale projects have created inefficiency and safety concerns. The small-scale mines are in particular a serious work safety hazard because they are cheaply run, lack modern equipment, and are too numerous for frequent inspections. The small power plants are far less efficient than large-scale operations. In recent years, the central government has made a concerted effort to close these down. However, it is still the case that small wind plants and small production facilities do not require national-level approval.

Major energy projects, including refineries, high-voltage transmission lines, and nuclear and hydro power plants, require national-level approval. As of April 2015, fossil fuel power plants require provincial project approval, although they must first be in the national plan. All decisions about primary resource development, such as international involvement in oil wells and coal mines also require national approval.

Innovation policy is dispersed among competing state agencies. While NDRC retains a great deal of power once technologies have reached the commercialization stage, in the R&D stage MOST plays a critical role, allocating most of the research funding under China's 863 (applied research) and 973 (basic research) plans. Research money is also funneled to CAS, which in theory is the ministerial equal of MOST. However, MOST not only funds university and company-based research, but also funds key laboratories that compete with CAS.

In addition to performing research, CAS and CAE both perform a critical role in evaluating and recognizing excellence in science. They act as the gatekeepers for academic standing. They are able to provide outside evaluation on scientific quality and to influence the direction of research funding. MOST's influence, however, is more direct, since it funds both its own plans and many academic and industrial research projects. MOST is very much a leader in promoting the idea of indigenous innovation and trying to reduce the amount of licensed technology in the energy sphere,

[187] The State Planning Commission was founded in 1952. It was renamed the State Development Planning Commission in 1998, and then became the NDRC in 2003.

although the effectiveness of this strategy varies considerably in different areas of energy technology.

Because energy projects are large, MOST alone cannot support energy innovation. One of China's greatest strengths in this area is its willingness to invest in large demonstration projects and in full-scale commercial deployment of new and relatively untested technologies. These projects require approval from NDRC, NEA, and other entities such as MEP and MLR. If projects are especially large or in strategically important areas, as many energy projects are, they will require State Council approval.[188]

Of course, many planned projects do not make it off the drawing board. Many locally-proposed energy projects, some with cutting-edge technology, are never implemented or have been subject to long delays. For example, localities proposed at least a half-dozen integrated generation combined cycle (IGCC) coal-fired power plants. This technology has been considered the best way to produce cleaner power from coal, since it is more energy efficient than conventional generation and pollutants are removed prior to power generation.[189] However, only one, the GreenGen project in Tianjin, a full scale IGCC with demonstration-sized carbon capture and storage (CCS) is well underway. The first-stage power plant is already completed. A second stage that will include further carbon capture is under construction, and this will be followed by a third 400 MW stage.[190] GreenGen has been led by Huaneng, China's largest power company. Other centrally-owned generation companies, coal companies, and investment companies have stakes as well. Given the cost, the central government has not approved other proposals.

Similarly, while provincial companies and governments have long lists of coal gasification projects for which they seek the go-ahead, observers expect that many will not be approved because of coal's environmental impact and China's efforts to cap its use.[191]

In the solar sector, more than ten solar thermal power plant plans have been announced in China, and yet there is little evidence of construction for most of them. For projects where costs are still being debated, technology is uncertain, or the environmental costs are significant, a local announcement will not necessarily lead to central government approval and actual implementation.

A number of other ministries come into play on international projects, which range from dam-building activity to oilfield development. At the very least, the Ministry of Foreign Affairs, MOFCOM, and the NDRC all have their stakes. Depending on the type of overseas operation and likely concerns, other bureaucracies (including the PLA, if there are national security concerns) might also be involved. As noted earlier, the size of the project often determines the level of central government involvement. There certainly are overseas investments that the central government is not fully informed about, but given the capital requirements for energy investments, this scenario

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188 "国务院关于发布政府核准的投资项目目录（2013 年本）的通知" [Notice of the State Council on Issuing the Catalogue of Investment Projects Subject to the Approval of Government (2013)], PRC Central Government website, December 13, 2013, http://www.gov.cn/zwgk/2013-12/13/content_2547379.htm.
189 Thomas W. Overton, "Does IGCC Have a Future?" *Power*, July 1, 2014.
190 Xu Shisen, "Moving Forward with the Huaneng GreenGen IGCC Demonstration," *Cornerstone*, Sep 30, 2014, http://cornerstonemag.net/moving-forward-with-the-huaneng-greengen-igcc-demonstration/.
191 "China Sets Cap on Energy Use," *Shanghai Daily*, November 19, 2014. Coco Liu, "Fossil Fuels: China Plans Major Slowdown of New Coal-to-Gas Projects in Bid to Cut Emissions," Climatewire, December 17, 2014.

in the energy sector is relatively rare. The balance of decision-making is not necessarily with the ministries, as SOE leaders may outrank them.

New regulations on outbound investment issued by the NDRC in 2014 have loosened up approvals overall, but there has been little impact on the energy sector. The typical size and sensitive nature of energy investments still require state vetting. Any transaction over $1 billion requires NDRC approval, while sums above $2 billion require State Council approval. Moreover, central SOEs in this sector automatically need NDRC approval. NDRC approval is also required for investments in industries deemed sensitive, including cross-border hydro and power and grid development, or in countries deemed sensitive, including both those lacking diplomatic relations with China and those with potential political problems, including civil war and unrest.[192]

The Make-up of China's Energy Industry

China's energy industry is dominated by large SOEs, particularly in traditional priority areas such as oil and nuclear. There is more diversity in areas where the Chinese government has been less concerned with shortages and international pressure, such as power generation and coal. The most open sectors are new energy sectors, such as wind and solar, which the government does not yet expect to produce large amounts of energy.

The Coal Sector

Coal mining is by far the most open part of China's energy industry sector, and coal prices are free of state control. Since the 1980s, the sector has been opened up to thousands of private and local companies as well as numerous provincial and local state-owned companies.[193] The one SASAC-controlled national coal SOE, Shenhua Coal, is ranked in the top two hundred of the Fortune 500 list. Shenhua produces more than 300 million tons of coal a year, about 7.5 percent of China's total annual coal production of nearly 4 billion tons. Shenhua and some of the larger provincial SOEs are diversified power companies, having invested heavily in mine-mouth power plants. It is also a world leader in coal liquefaction technology development.

In recent years, the Chinese government has cracked down heavily on small coal mines, closing thousands per year as part of a plan targeted in the 12th FYP.[194] The impetus has been both environmental and mine safety, which are intimately linked. Small mines are often cut in ways that endanger workers' lives and the land and water quality of communities surrounding them. The coal that small mines produce is also of lower quality, since the large SOEs control the better resources, and so they add disproportionately to China's urban air pollution problem.

The Petroleum Sector

The petroleum sector is concentrated and highly state-controlled; however, it is important to note that state control runs in both directions. There are three major companies in this sector: Sinopec,

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192 Covington & Burling LLP, "China Relaxes Approval Requirements for Outbound Investment," January 24, 2014, https://www.cov.com/~/media/files/corporate/publications/2014/01/china_relaxes_approval_requirements_for_outbound_investment.pdf.

193 Mark C. Thurber and Richard K. Morse, eds., *The Global Coal Market* (Cambridge: Cambridge University Press, 2015).

194 David Stanway and William Hardy, "China to Close Nearly Two Thousand Small Coal Mines," Reuters, April 4, 2014, www.reuters.com/article/2014/04/04/us-china-coal-idUSBREA330QQ20140404.

the China National Petroleum Corporation (CNPC), and the China National Offshore Oil Corporation (CNOOC). The heads of these companies tend to be high-ranking party members, which means that this sector is able to exert more pressure on the government than most industrial sectors in China. The leadership is less high-ranking after the Zhou Yongkang corruption scandal that toppled a number of senior petroleum executives, but it is still the case that the chair of Sinopec is a member of the CCP Central Committee.[195]

The assets of these companies, as detailed below, are divided such that they compete with each other on a very limited basis.

Ranked number 2 on the Fortune 500 list, Sinopec is the largest oil refiner in Asia and is ranked number 2 on the Fortune 500 global list. In the original 1983 oil company structure, Sinopec was responsible purely for downstream refining and product distribution. It now sees some competition in this sphere from CNPC and even from the much smaller CNOOC in the retail space. At the same time, Sinopec has been allowed to move upstream and is active in new areas, such as gas production. Sinopec CEO Wang Yupu is a member of the CCP Central Committee. Given the company's interest in localizing oil and gas technology, it is worth noting that Wang has a PhD in petroleum engineering. While most of his career was in the oil sector (including 20 years at the Daqing oilfield), he came to this position directly from being a deputy director of the CAE, where he is an academy member.

CNPC is the largest of the three companies and ranks fourth in the Fortune 500 list. Its international arm is PetroChina. When the oil sector was first divided in 1983, CNPC was put in charge of the onshore upstream sector, which involves petroleum exploration, development, and production. It continues to dominate this sector, but it now also has refineries. In addition, it is active in acquiring assets internationally in countries ranging from Peru to Sudan and South Sudan.[196] CNPC lost large numbers of senior managers in the wake of the Zhou Yongkang scandal. Its new CEO, Wang Yilin, is relatively low-ranking for the head of a Chinese oil giant, but comes from a posting at the CCP Central Discipline Inspection Commission.

CNOOC is the smallest of China's three majors and is ranked 72nd in the Fortune global 500 list. It was created purely to engage in joint venture offshore oil exploration at depths of 5 meters or greater (depths of less than five meters are defined as onshore and are the purview of CNPC). CNOOC Chairman Wang Hua and CEO Li Fanrong are both career CNOOC employees and are not members of the CCP Central Committee.

The company has been more ambitious in the past decade, attempting to develop its own deep offshore rig (shelved in 2015 when the price of oil fell) and to work with Brazil's Petrobras Corporation. It has also acquired interests in some US shale gas projects.

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[195] Zhou Yongkang was China's security chief when he was brought down by a corruption scandal in 2014. However, most of his career was in the petroleum sector, including serving as party secretary at CNPC. A large number of other CNPC employees were brought down after Zhou. Carrie Gracie, "Power Politics Exposed by Fall of China's Security Boss," BBC, June 11, 2015.

[196] Nick Snow, "China Reviewing Oil Relationships with Sudan, South Sudan, Researcher Says," *Oil and Gas Journal*, October 21, 2014, http://www.ogj.com/articles/2014/10/china-reviewing-oil-relationships-with-sudan-south-sudan-researcher-says.html.

CNOOC's largest attempt to diversify was the failed Unocal acquisition in 2005, where CNOOC withdrew after it became clear that it would not be able to survive the Committee on Foreign Investment in the United States process (the committee under the US Department of Treasury that reviews foreign investments). CNOOC's bid was likely to fail both because it was a state-owned enterprise and because it was from a sector in China where competition was limited. Although the review never took place, the deal's failure is still the subject of ill feelings among Chinese oil executives, who had not expected to face such opposition, especially since Unocal's assets were almost entirely outside of the United States. The negative outcome has made Chinese companies much more skeptical about whether US markets are completely open.

Although CNOOC was founded explicitly to work with international companies, all three corporations now engage in joint ventures both domestically and internationally in exploration and development, refining, and LNG terminals. Much of the traditional onshore oil development was the exclusive domain of CNPC, but in 1993 the Tarim Basin in Xinjiang Province was opened to joint ventures. It never came up to its anticipated level of production, however.

As China's domestic production has shifted from the exclusively state-owned Daqing field to the offshore ConocoPhillips-CNOOC joint venture Bohai field in the Bohai Bay east of Tianjin, international cooperation has only deepened. Major Western oil service firms like Schlumberger and Halliburton have long worked in the Chinese oil sector, and in most circumstances Chinese companies have relied on them for the sophisticated technologies needed to service offshore wells. There now is an ambition to increase the technical capacity of this sector and to see it move into new areas such as natural gas development, which has traditionally been quite weak because of poor policies and low supplies of traditional natural gas (discussed further in the section on natural gas).

China does not have any independent pipeline infrastructure. Pipelines are owned by the oil majors, and access to this infrastructure by other companies is difficult.

The Power Sector: Generation and Equipment

The Chinese power sector is dominated by state-owned firms at the national, provincial, and local levels. Prices are controlled, but there are large numbers of generating companies, resulting in considerable competition for government recognition and grid connections.

China's single national electricity company was divided in 2002 into generation and grid companies. The "Big Five" national generation companies formed—Huaneng, Huadian, China Power Investment Corporation, Guodian, and Datang—together produce less than 40 percent of China's total electricity. Three other generation companies now also have national prominence: Shenhua (a state-owned coal company and major power generator), China National Nuclear Corporation, and the Three Gorges Corporation. Added to the Big Five, national-level companies control slightly less than half of generation. Provincial and private or semi-private firms make up the rest, resulting in multiple options for provincial energy planners and the grid companies.

While all eight of the large generating companies ("gencos") are SASAC-controlled, only one of their CEOs, Huaneng's Cao Peixi, is a member of the CCP Central Committee. Huaneng has always been the largest and most powerful of the gencos. Its previous CEO, Li Xiaopeng, is the son of former Premier Li Peng. International firms are allowed to invest in the generation portion of the sector, but international investment is less than 10 percent of total investment in the sector, and very little of this investment is in wholly owned facilities.[197]

State Grid and Southern Grid are the country's only two grid companies, and they face controlled prices for electricity purchases and sales. While in theory there are two national grids, in reality very little electricity is sold between provinces. Each provincial grid essentially operates independently. A great deal of electricity moves across provincial lines, but this is mainly in the form of dedicated high-voltage lines from hydropower projects in western China to high energy consuming provinces in the south and east. Both State Grid and Southern Grid are SASAC-controlled companies. While the current chairman of State Grid Liu Zhenya was an alternate member of the CCP 17th Central Committee, he was not a member of the 18th Central Committee.

NDRC has announced plans to reform State Grid and Southern Grid, ultimately leading to separate transmission and distribution companies, a move that is expected to take years to complete. At the same time, the grid companies and the generating companies themselves will also be allowed for the first time to make bulk sales to industrial users, rather than selling only according to set tariffs established by NDRC.[198] These moves are expected to lower the cost of industrial electricity, which has been high by world standards.[199] To date, the grid companies have benefited from controlled prices, while the gencos have often been squeezed by the variable coal price on the one hand and fixed prices for sale to the grid on the other. If distribution is opened up as planned, this could benefit gencos and reduce the power and wealth of the grid companies.

China is a major player in hydropower construction and development, with large SOE construction and development companies such as Sinohydro, Three Gorges, International Water and Electric, and Gezhouba (International Rivers) building and operating hydropower dams in China and other countries.

Likewise, China has an ambitious nuclear plan entirely dominated by SOEs with international cooperation. The Chinese government has restricted nuclear development to two SOEs, China National Nuclear Corporation (CNNC) and China's State Nuclear Power Technology Corporation (SNPTC), both under direct SASAC supervision. A limited number of gencos are allowed to build and operate nuclear power plants. One major impetus for these restrictions appears to be to ensure strict safety and quality supervision.

In July 2015, SNPTC merged with China Power Investment Corporation to become State Power Investment Corporation.[200] This move was reportedly intended to enhance export ambitions. While China's nuclear development has involved substantial international cooperation, including the licensing of Areva technology for its second-generation plants and the purchase of Westinghouse technology for the third generation, the explicit ambition is to produce a wholly domestic design.

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[197] The Regulatory Assistance Project, *China's Power Sector: A Backgrounder for International Regulators and Policy Advisors,* February 2008.
[198] Aizhu Chen, "China Extends Pilot Power Sector Reforms to More Regions," Reuters, April 15, 2015.
[199] Author interview with Ning Zhang, Lawrence Berkeley National Laboratory, September 10, 2015.
[200] Sonal Patel, "China's Nuclear Power Companies Merge to Strengthen Export Ambitions," *Power Magazine,* June 3, 2015, http://www.powermag.com/chinas-nuclear-power-companies-merge-to-strengthen-export-ambitions/.

A key part of the power supply is the production of the equipment that generates the power. These companies are central to China's strategies for indigenous innovation and for how it accesses international technology. The corporate structure for power generation equipment manufacture is as follows:

- **Traditional generation equipment:** The more traditional coal and hydro generation markets are dominated by major SOEs, several of which are large SASAC-controlled companies. These are firms that have long been fostered by the central government, such as Harbin Electric and Dongfang Electric. However, today there are also a number of provincial-level SOEs, such as Shanghai Electric, that compete in this space as well.
- **Natural gas turbines:** China mainly imports natural gas turbines as local manufacturers are unable to provide the same level of quality.
- **IGCC:** Coal gasification is an area where until recently China imported most of its equipment, but it now has competitive domestic manufacturers particularly for gasification equipment. However, turbine quality for IGCC projects is still an issue, and whether Chinese turbines meet specifications depends on the level of quality demanded for specific projects.
- **Wind power:** China is a major wind power manufacturer, which is a diverse sector with both state-owned and private companies. None of the SOEs yet rank as major players in the traditional energy sector. Many, however, have received assistance from both provincial and national plans.
- **Solar power:** The solar sector has developed independently of central government involvement, and many of the major players are private firms. Originally, they focused on the international market, especially in places that offered solar power subsidies, like Germany and California. Since the 2008 financial crisis, China has increasingly offered support for solar buildout domestically, and many solar firms are now also focused on the domestic market. As detailed in the section on solar technology, China's main product is a commodity silicon cell, but there is interest in expanding into new technologies.

Chinese Views of the Global Energy Context

In the 12th Five-Year Energy Development Plan, the Chinese government outlines its views of the context in which energy policy is made. This has implications for the United States because the fundamental Chinese outlook is of competition and short supply. China sees most of the international interaction as "pressure," whether that is competition for resources and technology, or international pressure on China for a greater response to climate change.

At the same time, the Chinese authorities view their domestic situation as a significant constraint on their energy options. The 12th FYP states that the prospect for "energy security is grim." This reflects the fact that China has only 6 percent of the world's oil reserves. The FYP estimates that crude production can be maintained only at 200 million tons (1.5 billion barrels) per year, and that domestic natural gas supply can meet only 30 percent of new demand. Chinese policy focuses both on the inevitability of rising petroleum imports and specific concerns with the lack of control not only over oil assets but also over sea lanes used to transport oil.

The one bright spot from a supply point of view is coal, where supplies are plentiful. Coal use, however, is constrained by its adverse environmental impact. The 12th FYP states that "the green economy is pressing," and provides a list of environmental challenges. They include overdependence on coal, excess use of water and water contamination, energy production byproducts contaminating soil and wasting land, acid rain, and the world's highest emissions of major pollutants and greenhouse gases. In the international context, the 12th FYP expresses concerns about pressure, but once it turns to domestic concerns, it says quite frankly that the current model is environmentally unsustainable. From the domestic perspective, opportunities for complementarity with other countries' energy plans, including those of the United States, increases dramatically. The concern for reducing environmental impacts speaks to a shift from dependence on fossil fuels, especially coal, and to China's growing emphasis on renewables, nuclear energy, and energy efficiency.

Energy efficiency is the first core concern in the FYPs. Most recent planning indicates an important shift from previous plans, particularly the 11th FYP with its sharp focus on the energy efficiency sector. The improvements achieved under the 11th FYP were remarkable. Most notable was an overall 19.1 percent reduction in energy intensity (energy consumption per unit GDP), achieved through a rigorous command and control plan focused on the most energy-intensive heavy industry sectors. Specific technology and process mandates included appointing energy managers and establishing checklists for large companies, along with closures of thousands of small, inefficient operations in the power, cement, and iron and steel sectors.[201]

Sectoral shift was a major mandate in the 12th FYP, in contrast to the 11th FYP. The 12th FYP mandated a shift away from the energy-intensive heavy industrial economy, specifically iron and steel, nonferrous metals, building materials, and the chemical industry. This shift in sectoral emphasis follows on what has long been an international recommendation for the Chinese economy to "rebalance."[202] Until recently, this effort has been unsuccessful. However, there are indications that a real shift is now taking place in the service sector and also possibly in the higher value-added manufacturing sector, as opposed to both primary commodities and export processing.

Some analysts argue that pessimism about China's current economic slowdown is a misreading of this shift.[203] A shift of even a few percentage points to the service sector from heavy manufacturing has a much greater impact on overall energy consumption than do more technical fixes within those sectors. Consequently, the recent fall-off in electricity demand in China could bode well for a more fundamental change in the overall economy.[204] Power consumption in 2015 rose a mere 0.5 percent to 5.55 trillion kWh, compared to a 3.8 percent increase in 2014.[205] Continued slowing electricity growth seems likely, as power production actually fell in 2015 and the Chinese economy continues to shift away from heavy manufacturing. Moreover, China's great infrastructure build-

[201] Lynn Price, Mark D. Levine, Nan Zhou, David Fridley, Nathaniel Aden, Hongyou Lu, Michael McNeil, Nina Zheng, Yining Qin, and Ping Yowargana, "Assessment of China's Energy-Saving and Emission-Reduction Accomplishments and Opportunities During the 11th Five-Year Plan," *Energy Policy* 39, No. 4 (2011): 2165–78.
[202] Nicholas R. Lardy, "China: Rebalancing Economic Growth," paper for the *China Balance Sheet* series, Peterson Institute for International Economics and Center for Strategic and International Studies, 2007.
[203] "Why Chinese Economic Worries Look Overdone," *Economist,* August 21, 2015.
[204] Matthew Nitkoski, "Electricity Use Trends Point to Major Gains in China's Energy Efficiency," *China Economic Review,* August 24, 2015.
[205] "China's Slowing Power Consumption Highlights Clean Energy Gains," *Bloomberg News,* January 18, 2016; "China's 2015 Power Consumption Up 0.5 Pct Year-on-Year," Reuters, January 17, 2016; David Stanway, "Update 2: China 2015 Power, Steel Output Drop for First Time in Decades," Reuters, January 18, 2016.

out is reaching completion, as already evidenced by the surpluses in steel, cement, and other building materials predicted in Lawrence Berkeley National Laboratory's models of Chinese energy demand.[206]

This overall economic shift to the service economy will likely benefit global environmental efforts. The shift supports China's efforts to let carbon emissions peak in the 2020s. It also is likely to encourage current efforts to reduce local air pollution, as services are best marketed from modern, attractive cities. There will be more global competition in these sectors as Chinese services develop. This will probably take time, however, as this has been an undeveloped portion of the market. More global competition in heavy industry would be expected as well. A recent report by the East-West Center found that while the Chinese service sector has grown quickly in the last three years, it still has a 13 percent lower share of GDP than is typical of a country at its level of per capita GDP.[207] As domestic demand for China's heavy industrial products declines, a huge effort is already underway in plans such as One Belt, One Road to create an international market for these products.

Energy infrastructure is China's third domestic policy priority. While the build-out for rail and roads may be nearing completion, energy infrastructure is still a concern. Much of this concern focuses on electricity, with improvements to long-distance transmission, local grids, and distribution to consumers; moving more energy across provincial lines; and reducing service disparities between urban and rural areas. New pipelines are also under consideration, especially as part of efforts to encourage natural gas use. The latter has international implications, as a major issue is the difficulty of negotiating deals with Russia. Although one pipeline is under construction, the fate of the overall 2014 deal with Russia is still uncertain, due in part to fluctuating natural gas prices.

Technology is the fourth critical area. The overall environment is stated as a need to focus on low-carbon technologies, including a shift to renewables and natural gas. This effort again complements global environmental efforts, but China's various energy S&T plans highlight its indigenous innovation efforts. The desire is to use local technology to the largest extent possible. This often puts Chinese policy in conflict with other countries' goals to sell more technology. It is worth noting that the United States is not the only country affected by this effort, and, depending on the technology, may not see the largest impact.

Energy system reform is the final overall area. Key reform goals are reducing monopolies and the prominent place of coal in the system and ensuring that new and renewable energy sources are effectively integrated into the grids. Limited progress has so far been made in reducing monopolies. Current reform at State Grid may have some impact, but mainly in the form of shifting retail electricity sales to separate entities, not breaking up the transport network. Surprisingly, there has been virtually no reform of the oil and gas commercial structures, even in its weakened state after

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[206] "China's Power Consumption Surges in August," *CRI English*, August 31, 2015; Nan Zhou, David Fridley, Michael McNeil, Nina Zheng, Jing Ke, and Mark Levine, "China's Energy and Carbon Emissions Outlook to 2050," Lawrence Berkeley National Laboratory, April 2011, https://china.lbl.gov/sites/all/files/lbl-4472e-energy-2050april-2011.pdf.

[207] Wei Wang et al., "Beyond Manufacturing: Developing the Service Sector to Drive Growth in the PRC," *AsiaPacific Issues* 124, May 2016, http://www.eastwestcenter.org/system/tdf/private/api124.pdf?file=1&type=node&id=35640.

the fall of Zhou Yongkang. The central government is missing out on this golden opportunity to curb the monopolistic powers of a politically weakened oil and gas sector, and it appears unlikely that it will be able to undertake such reforms in the foreseeable future.

A shift away from coal is already in progress. The shift will be slow, but the growth of nuclear power and renewables means that it will happen over time, with this shift resulting in China's peaking its greenhouse gas emissions some time before 2030. Similarly, the grid integration issues for renewables in particular are real, particularly problems with fluctuations and managing diverse sources. Much of the emphasis on "smart grid" is really an effort to resolve these problems. Price reform, the most obvious portion of market reform, is not mentioned in these plans, and there is relatively little action on this front.

China's energy system is a mixture of more market-driven prices, in particular the price of raw coal, and controlled prices. Many of these price controls are responses to the monopoly conditions of both the grid system and the oil market. Despite this overall structure, there are some ways the Chinese authorities could reform electricity prices without becoming hostages to monopoly pricing. The first is that the generation companies are competitive. This is not a concentrated sector. The series of electricity market reforms over the course of 2015 will allow for some limited competition in that the generating companies will be able to sell their power directly to industrial customers.[208] Whether they will be able to negotiate prices with the grid companies is not as clear. China's challenge is to come up with a way to enable more competition without favoring cheap coal. Currently, electricity dispatch rules, the rules by which State and Southern Grid are required to purchase power, specify when more expensive, but cleaner, sources are required.

A second opportunity for price reform would be to bring in time-of-day and other peak pricing measures. In general, Chinese demand-side management efforts have been hobbled by lack of flexible pricing in both electricity and oil and gas. With growth in both consumer and service sector demand, flexible pricing could be a significant energy efficiency tool, but it does not appear to be as high on the Chinese government's wish list as new technology.

Market Demand

China is now the second largest economy in the world and overall the second largest energy consumer after the United States. Consequently, its largest impact on the United States is simply as a large player in the market. However, fossil fuel markets are highly volatile and subject to many other influences besides changes in demand. Indeed, demand changes tend to be fairly slow and predictable in comparison to political changes in supplier countries, new finds, and other supply changes that affect markets. Nevertheless, China's large and growing influence on the global energy market is a predictable part of the global energy future.

Demand for Coal

China has plentiful supplies of coal, which means that imports are likely to continue to be a small fraction of total consumption. Coal imports currently stand at less than 4 percent of the total Chinese coal market, and coal imports declined by 30 percent in 2015.[209] China's influence on the

[208] Aibing Guo, "China to Break Electricity Distribution Monopoly Over Sales," *Bloomberg Business,* November 29, 2015; "China Extends Pilot Power Sector Reform to More Regions," Reuters, April 15, 2015; "China Issues Rules to Reform Electricity System, NE21.com says," *Bloomberg Business,* March 22, 2015.

[209] "China's Slowing Power Consumption Highlights Clean Energy Gains," *Bloomberg News,* January 18, 2016.

global coal market is relatively small, and there is nothing in the various planning documents to suggest any policy to change this. However, given the relatively poor quality of Chinese coal, it is conceivable that at some point there may be more demand for higher-quality foreign coal, especially for its power plants. There are potential suppliers in the Asia Pacific region, including Vietnam, Indonesia, and Australia. One question is whether at some point US coal might also be of interest. While the amount might be small, this could conceivably become a flash point at West Coast ports given the concerns of US environmentalists. At the very least, any expansion of coal export port capacity would be likely to get mired in years of licensing and challenges to environmental impact studies. Given the decline in Chinese demand, an uptick in US exports seems relatively unlikely despite some interest in coal-producing regions.

The more near-term changes are China's commitments to: 1) reduce greenhouse gas emissions, especially reducing carbon intensity 17 percent by 2020 and topping out total emissions by 2030 if not earlier; 2) improve ambient air quality in its large urban regions, including lowering the air pollutant PM2.5 by 2017 in the Beijing area by 25 percent, in the Shanghai region by 20 percent and in the Pearl River Delta by 15 percent; and 3) cap total coal consumption at around the current level of 4 billion tons per year by 2020.[210]

The net result of these commitments and plans is that coal consumption is unlikely to ever go much higher than its current level, and what coal is used will be employed with increasing efficiency. China has already mandated substantial improvements in industrial efficiency, and these standards will continue to be raised. The current target for electric power, which uses 50 percent of China's coal, is that new power plants use no more than 300 grams of coal per kilowatt hour (KWh as China committed to in its June 2015 submission to the UN Framework Convention on Climate Change). Moving away from simple supply-side efficiencies, current efforts have also focused on improving grid efficiency in both lines and transformers, and building energy efficiency as commercial and residential use becomes a greater part of the rebalanced global economy.

From an environmental perspective, these changes will be positive for the efforts of all countries, including the United States, that seek to reduce climate gases and other pollutants. However, it is important to consider the follow-on effects in other energy sectors. Attempts to limit coal consumption will mean increased demand for other fuels.

Demand for Natural Gas

China's expressed goal is to increase natural gas use by 10 percent annually to reach 10 percent of total primary energy consumption by 2020. However, demand grew by only 5.7 percent in 2015,

[210] PM2.5 is particulate matter less than 2.5 micrometers in diameter. The smaller the particle, the easier it is for it to pass through the lungs and into the bloodstream, causing greater health damage. Current air pollution policies focus on these tiny particles. Some PM2.5 is produced directly from combustion, but more of it is a secondary pollutant in the air, produced from a number of primary pollutants, including sulfur dioxide, nitrogen oxides, and volatile organic compounds, all of which are emitted at various stages in energy production and consumption.

and most of that was due to a late in the year price cut.[211] The Chinese government's own projection for increased demand in 2016 is a modest 6.1 percent.[212] The Chinese government had raised natural gas prices to encourage gas project development, but with world oil prices low and pushing down the price of coal, natural gas is now overpriced. Observers expect the Chinese government to lower the natural gas price shortly. However, this type of inflexible pricing model is one of a number of institutional challenges to the expansion of supply.[213]

China has some of its own natural gas, but projected expansion in consumption depends on multiple additional sources, including coalmine and coalbed methane, shale gas, piped gas from Russia and Central and Southeast Asia, and LNG imports. None of these sources have grown as fast as projected. While China will seek to import more gas, its demand growth and impact on world markets will be relatively modest. China's international purchases are generally pure market transactions and are likely to have little impact on the United States as the latter has its own supply of domestic gas and is little affected by international pricing. The one question might be Russian gas, where both countries would stand to benefit politically from a strong gas-trading relationship. However, by all accounts, China and Russia are having trouble moving forward with their bilateral gas deals precisely because of the volatility of the market. They are also having trouble with price discovery. In other words, given the limited number of deals and the volatile market neither side is comfortable with where the price is likely to be in the future.[214]

Because of its high cost, natural gas in China is generally used by households rather than industry, as there is a strong cultural preference for cooking over a flame. There has been some growth in gas-fired power plants, but they are still a small fraction of the total number of plants in China. Natural gas is rarely used in industrial applications due to its high costs. As a result, China's petrochemical industry relies heavily on coal gasifiers rather than natural gas.

There are a number of industries, such as glass and cement, where shifting from coal to natural gas would be important in raising quality because gas provides more consistency, leading to more uniform firing characteristics. As China seeks to move up the value chain, these types of shifts will be important, but so far manufacturers have resisted because of the high price of gas.[215]

Demand for Nuclear Power

The Chinese government has long been interested in developing civilian nuclear power. Nuclear energy offers both environmental and energy security advantages. On the environmental front it produces neither local air pollutants, nor greenhouse gases, and while neither of these issues were prominent considerations when the Chinese government began to encourage the development of the nuclear sector, they now make it particularly attractive. Nuclear energy's advantage for energy security, a concern of much longer standing, is the ability to diversify supply in ways that are a useful balance to both coal and oil.

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[211] Aibing Guo and Sarah Chen, "China Diesel Use Slumps as Natural Gas, Gasoline Demand Gains," *Bloomberg News,* January 24, 2016, http://www.bloomberg.com/news/articles/2016-01-25/china-diesel-use-slumps-as-natural-gas-gasoline-demand-gains.
[212] Adam Rose, "China Sees Energy Consumption Rising in 2016," Xinhua, December 29, 2015.
[213] Author interview with Erica Downs, the Eurasia Group, August 24, 2015.
[214] Author interview with Edward Chow, Center for Strategic and International Studies, August 28, 2015.
[215] Author interview with Fuqiang Yang, Natural Resources Defense Council, August 23, 2015.

Nuclear power is a viable substitute for coal in the Chinese power industry. The target in the 12th FYP was 40 GW of installed capacity by 2015. The Chinese authorities are developing nuclear power rapidly, but in general they have not executed their most ambitious plans. Moreover, current plans were slowed specifically by a safety review after the 2011 Fukushima accident. That review was completed by mid-2012, and certification of new plants resumed.[216]

According to the International Atomic Energy Agency's (IAEA) database, as of 2014, there were 28 operational plants in China with approximately 25 GW installed capacity and another 24 GW under construction with an equal amount of installed capacity.[217] From these figures, it is unclear whether the 40 GW target would have been reached by the end of 2015, but the 2020 target of 58 GW looks to be more easily obtainable. This 2020 goal is scaled down from earlier goals of 70−80 GW installed capacity.[218]

When the relatively slow rate of growth in nuclear power over the 1990s and early 2000s is examined, combined with the four-year pause after the 2011 Fukushima accident and public discussions of safety, it appears that China's ambitious nuclear goals have been curtailed to ensure feasibility within safety parameters. Chinese planners emphasize safety far more consistently when related to nuclear power than any other energy sector. In fact, the nuclear section of the 12th five-year energy plan is the only area where "safety first" is a stated part of the plan.[219] The five-year planning process includes a separate nuclear safety plan with specific targets for numbers and types of inspections and the issuance of new safety regulations. Since the start of the 12th FYP (with the exception of the Fukushima review), there has been a clear increase in the speed with which new plants are being opened.[220]

In contrast to oil, where much of the Chinese supply involves significant political risk and where China has come under international criticism for supporting unsavory regimes, China has a number of options for purchasing nuclear fuel. The sources are both more politically diverse, ranging from Australia to Central Asia, and closer to China. Consequently, while the Chinese goal is to increase its self-reliance, uranium sourcing appears robust and diverse enough to reduce energy security concerns. Currently 25 percent of nuclear fuel originates from domestic sources.[221] China is developing new domestic mines, however, and plans to raise the domestic supply to meet one-third of demand although the target date for these plans is unclear. It is also unclear whether the Chinese government will be able to meet this goal since some experts believe China has only 1 percent of total recoverable reserves and that these supplies are of poor quality. Under these circumstances,

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[216] Yun Zhou, "China Responds to Fukushima," *Bulletin of the Atomic Scientists,* June 28, 2012.
[217] "China, People's Republic of," IAEA Power Reactor Information System database, https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=CN.
[218] "China Nuclear Body Recommends 2020 Target of 70 GW," Reuters, November 23, 2010.
[219] The word "safety" was added to the main target of "steady development" after Fukushima. World Nuclear Association, "Nuclear Power in China," updated January 2, 2016. In reporting the resumption of nuclear construction, the CCP-affiliated *Global Times* presented views that safety was still a concern. See Zhang Yu, "China Resumes Nuclear Power Plant Construction After a Four-Year Freeze," *Global Times,* June 15, 2015.
[220] "China, People's Republic of," IAEA Power Reactor Information System database.
[221] World Nuclear Association, "China's Nuclear Fuel Cycle, "updated July 2015, http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Fuel-Cycle/.

some analysts estimate that Chinese uranium imports could constitute 17 percent of global demand by 2020.[222]

China is also becoming more independent in nuclear technology. While its second-generation nuclear power plants are based on Areva technology that still requires license fees, its third-generation CAP1400, a passive 1400 MW design based on the Westinghouse AP1000 (now owned by Toshiba), is purchased foreign technology. The agreement with Westinghouse specified that the Chinese would own the technology and any improvements, and could use it domestically and for export of any power plant larger than 1,350 MW.[223] The Chinese say they now have fully indigenous IP.[224] Moreover, when looking at beyond third-generation technology, China is now leading global research efforts (see Nuclear Technology section). As a result, nuclear technology looks to be an area where China will not only become self-sufficient, but is striving to become a major exporter. This means that China is no longer an attractive nuclear customer but instead is a major competitor to the United States and other major nuclear exporters.

Given that total installed capacity of coal-fired power plants in China is over 900 GW, nuclear power currently only substitutes for coal at the margins. Hydropower is another major clean alternative power source, with over 300 GW of installed capacity in China. But nuclear energy is the Chinese government's preferred long-term play, and it is growing far more rapidly than natural gas, while coal development is slowing and will likely taper off soon with the 2020 coal cap.

Demand for Renewables

Renewables are growing rapidly as well, but it is worth noting that installed capacity numbers are not directly comparable to fossil fuel and nuclear power plants. While fossil and nuclear energy can run close to 100 percent capacity (with some breaks for maintenance, and China's plants are running at considerably less than full capacity during the current economic slowdown), a well-run wind or solar plant in optimal conditions might only reach around a 30 percent utilization rate because the sun does not always shine, nor the wind always blow. Chinese solar and wind plants though run at lower capacities. For example, in the wind sector, Chinese plants run at little over 20 percent capacity, while US plants run at around 33 percent.[225] Consequently, while nuclear installed capacity is well below that for both wind and solar, actual electricity generated by nuclear plants already is likely to exceed that of solar power generation, and may well meet that of wind power within the next decade.

Demand for renewables is driven more by government policy through targets in the FYP than by market demand. The Chinese solar industry had already exceeded the 12th FYP target of 21 GW installed solar PV in 2014, and reached 43 GW of installed capacity in 2015. This represents ex-

[222] Pascale Massot and Zhan-ming Chen, "China and the Global Uranium Market: Prospects for Peaceful Coexistence," *Scientific World Journal,* 2013.
[223] Clark Edward Barrett, "Chinese 3rd Generation Nuclear Technology Development," *China Brief* 14, No. 8, April 23, 2014.
[224] Sharryn Dotson, "China's Nuclear Boom," *Power Engineering*, August 25, 2015.
[225] "What Are the Capacity Factors of America's Wind Farms?" *Carbon Counter, Observations on Energy and Climate Change with Robert Wilson*," July 24, 2015, https://carboncounter.wordpress.com/2015/07/24/what-are-the-capacity-factors-of-americas-wind-farms/

traordinary growth. In 2015 alone, the Chinese solar industry installed at least 15 GW, and reportedly as much as 16.5 GW.[226] At the beginning of this FYP period in 2011, China had less than 1 GW of installed solar capacity (Table 5, pp. 74−75).

The overall goals are ambitious. While already the world leader in installed capacity, Chinese wind power is targeted to reach 200 GW installed capacity and solar 100 GW by 2020. This is an especially heavy lift for solar power, since the goal is 21 GW by the end of the 12th FYP, but solar is developing rapidly after a relatively late start. Development plans for solar include large-scale grid-connected development in North Central and Western China, with 10 GW planned for each area. In addition, there is a new emphasis on microgrids, with a push (still in its infancy) to develop small-scale distributed power.[227] Wind development began much earlier than solar in China, and as of the end of 2015 China had 129.3 GW installed around the country.[228]

Most renewable energy in China relies heavily on local manufacturers and technology. Chinese firms have been major players in solar cell fabrication globally, and while some of its cells are not as technologically efficient as those of competitors, when compared by cost per kWh they are actually very cost effective.[229] According to the International Energy Agency, China produced 61 percent of photovoltaic cells and 66 percent of photovoltaic modules in 2014. China was also the largest consumer with 27 percent of the market, and its installed capacity is now second behind Germany and growing much faster. The United States has a much smaller share of the production market with only 2 percent of photovoltaic cells and modules.[230]

Because of the large size of the components, most wind energy technology is built close to where the demand is centered. This has allowed China to establish a large wind-manufacturing sector and with clear, long-term goals its businesses have been able to invest and expand the manufacturing base. Chinese companies engaged in strategic partnerships in the 1990s and early 2000s, especially with European wind manufacturers, but at this point they operate mainly on their own.[231] Chinese firms are likely to fulfill the demand created by the current five-year and 2020 renewables goals.

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[226] Jocelyn Timperley, "Chinese Solar Capacity Outshone Germany's in 2015," *Business Green*, January 21, 2016; Tim Buckley, "Wind and Solar Records Tumble as China and India Accelerate Energy Transition," *RE new energy*, January 22, 2016.

[227] As defined by the Department of Energy's Microgrid Exchange Group, "A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode." Office of Electricity Delivery and Energy Reliability Smart Grid R&D Program, "DOE Microgrid Workshop Report," August 2011, http://energy.gov/sites/prod/files/Microgrid%20Workshop%20Report%20August%202011.pdf, 1. See also Ward Bower et al., "The Advanced Microgrid: Integration and Interoperability," Sandia Report SAND2014-1535, March 2014, 11, which acknowledges that "[m]icrogrid concepts and definitions are in flux" and have been expanded as the concept matures.

[228] Global Wind Energy Council, "Global Wind Report: Annual Market Update 2014," April 2015, 38, http://www.gwec.net/wp-content/uploads/2015/03/GWEC_Global_Wind_2014_Report_LR.pdf.

[229] Author interview with Jonas Nahm, Massachusetts Institute of Technology, August 28, 2015.

[230] International Energy Agency, *Trends 2015 in Photovoltaic Applications, Survey Report of Selected IEA Countries between 1992 and 2014*.

[231] Author interview with Jonas Nahm.

Demand for Oil

Demand can be expected to increase for imported oil to fuel the growth in transport, especially personal vehicle ownership. In the short term, the Chinese government has no expectations about increases in domestic production, with the 12th FYP projecting output to be flat. However, the Energy Development Strategy Action Plan (2014–2020) suggests that the government would still like to see steady increases in oil production over the medium term. The British Petroleum (BP) Energy Outlook 2035 projects Chinese oil consumption to more than double by 2035.[232] Whether growth is that high will depend to a significant extent on whether vehicles continue to run on petroleum or whether China's electric vehicle programs succeed in replacing this demand.

Regardless of long-term trends, in the short to medium term, China will continue to increase oil imports. The recent liberalization of crude imports by so-called teapot refiners (small refiners mainly in Shandong) also means that crude importation has become easier. Whether China also produces more domestically is a larger question. The US Energy Information Agency reports that expanded production in China would require the development of tight oil and deep offshore oil.[233] Both of these are difficult prospects in the existing low-price environment.[234] While CNOOC has been exploring deep offshore, analysts do not see large-scale development to be likely without an increase in prices.[235]

Chinese energy plans have multiple approaches to curbing the increased demand for oil. The national target is to have 30 percent of urban traffic in the form of public transport by 2020. Even with enormous public transport efforts, including the construction of metros in 35 cities, the Chinese Electric Vehicle Plan projects that there will be 150 million passenger vehicles (of all engine types) on the roads in 2020 and 250 million in 2030.[236] In addition to plans for EVs, there are also efforts around non-food-based ethanol, biodiesel, and other alternative fuels, but these are in the early R&D phase at present. While significant efforts are being made to reduce dependence on imported oil, none of these initiatives are a short-term fix. Chinese policy on liquid fuels can be expected to continue to seek secure oil sources internationally, and oil demand will be a significant factor in shaping Chinese attitudes toward Africa and the Middle East. Analysts see international acquisitions by Chinese companies as similar to those of other oil giants. While a decade ago the Chinese focus internationally was mainly CNPC acquiring equity in developing countries, today Chinese companies pursue a variety of strategies in terms of both type of purchase and the part of the supply chain, with interests both upstream (exploration and development) and downstream (production and products).[237] CNPC's investments in Sudan have been among its most controversial, and it has continued to operate there throughout its civil war. It has signed new agreements

[232] British Petroleum, "BP Energy Outlook 2035," February 2015, 45, http://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2015/Energy_Outlook_2035_booklet.pdf.
[233] "Tight oil" is the technical name for what is often known as shale oil in the United States, because much of it is found in shale formations. However, in China, in addition to sometimes occurring in shale, it also occurs in tight sandstone and tight carbonate rocks. Cai-neng Zou et al., "Geological Characteristics and 'Sweet Area' Evaluation for Tight Oil," *Petroleum Science* 12:606–17, October 14, 2015.
[234] EIA Beta, "China," updated May 15, 2015, http://www.eia.gov/beta/international/analysis.cfm?iso=CHN.
[235] Author interview with Edward Chow.
[236] Mark Fulton et al., "China's Green Move: Vehicle Electrification Ahead," Deutsche Bank Group, August 8, 2012, 12, https://www.db.com/cr/en/docs/China_GreenCars_080712.pdf.
[237] "Chinese Companies Pursue Overseas Oil and Gas Assets," *Oil and Gas Journal*, April 18, 2005.

with both Sudan (2015) and South Sudan (2014), and continues to be the major international player in that region. [238] However, many Chinese investments are far less controversial. The two largest have been outright purchases: the $15.1 billion purchase of the Canadian company Nexen by CNOOC and the $7.24 billion purchase of the Swiss company Addax by Sinopec.[239]

Indigenous Innovation

Indigenous innovation, essentially China's "go it alone" policy focused on producing technology with domestic IP, is a key goal in the 12th FYP, the MLP, and the individual plans for the energy sectors. The stated goal is to have Chinese technologies that are commercially dominant in every sector. There are clearly some sectors where Chinese technology is the global leader, such as coal-fired power plants and high-voltage long-distance transmission lines. In other sectors such as wind and solar technology, China is commercially dominant, but this may have more to do with cost than technology. In other areas, including much of the oil and gas industry, while plans state the intention to use local IP, the industry still uses a great deal of international technology. The Chinese government is also the world's largest state investor in energy R&D. Kelly Sims Gallagher, senior policy advisor in the White House Office of Science and Technology Policy, estimates that "the Chinese government appears to be investing approximately three times as much as the US government in energy R&D."[240] There is likely to be considerable variation in the stated plans, however.

One key point is that China's commercial dominance in many sectors is also in large measure due to the size of its market. In the past decade, overall energy consumption has more than doubled. As a result, China has been a major global consumer for almost all energy technologies. In many, including most parts of the power sector, such as generation, transmission, and pollution abatement equipment, it has been the dominant consumer. China's advantages as a low-cost manufacturer are compounded when its companies are also close to its consumers, reducing logistical costs and offering the possibility of greater responsiveness.

Coal Mining

Improving coal mining technology is a key technology target for China. While deaths have declined rapidly in recent years, China's coal mine death rate continues to be the world's highest.[241] The Chinese government has addressed part of the problem by closing small and private mines and consolidating other mining companies. Consolidation makes mine inspection more feasible and is intended to ensure that mining companies have sufficient funds to invest in better and safer equipment.

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[238] "Sudan Signs Six-Year Oil Exploration Deal with China," *Sudan Tribune*, January 30, 2015; Nicholas Bariyo, "South Sudan Signs Agreement with China's CNPC to Boost Oil Production," *Wall Street Journal*, December 22, 2014.

[239] "China's Sinopec to Buy Addax for C$8.27 Billion," Reuters, June 24, 2009; David Blumental, "The Changing Nature of China's Global Oil and Gas Deals," *China Economic Review*, August 8, 2014.

[240] Her estimate, however, is derived from an incomplete figure that did not include support for renewable energy, electricity transmission, distribution, or storage. Kelly Sims Gallagher, *The Globalization of Clean Energy Technology: Lessons from China* (Cambridge, MA: MIT Press, 2014), 42.

[241] "Shaft of Light: The Coal that Fuels China's Boom Is Becoming Less Deadly to Extract," *Economist*, July 18, 2015. The article points out that the rate per unit of coal is still ten times that of more developed countries, but the rate per 10,000 workers is now equivalent. China's coal extraction is more labor-intensive. Moreover, these rates do not include deaths from black lung, which are high, given that most of China's coal is underground.

The result has been some significant opportunities for international companies, and a number of US heavy-equipment firms are active in this sector. As with any sector in China, investing is not without risk, as was demonstrated by Caterpillar's massive write-off and allegations of fraud at a Chinese mining machinery company it purchased in 2012.[242] However, a large number of firms, including Caterpillar, are active in this space and continue to produce equipment in China for sale to Chinese coal-mining firms. Chinese mines today seek to be more mechanized, reduce their workforces, and capture coalmine methane for both environmental and safety reasons. While official plans stress developing more domestic technology, it appears that upgrading has been a higher priority than domestic sourcing, and that a number of US companies are sufficiently ensconced in the Chinese market that they are able to maintain sales. As noted earlier, coal mining itself is peaking in China and total output will decline over the next decades. This will mean that demand for new mining equipment will not be as robust over the longer term, while Chinese firms will also become more competitive.

Coal-fired Power Plants

China is already a world leader in coal-fired power plant technology, and its energy plans commit to still further improvements. This consistent effort has extended since the early 1980s, and continued investment can be expected.[243] Three areas are highlighted in the country's long-term plans:

- improving efficiency in critical power plant technology, where China is already the world's leader;
- improving fluidized bed technology, which is a technological solution to the cost of end-of-pipe pollution abatement; and
- development of IGCC with carbon capture technology.

China already leads the world in the production and sale of conventional and super critical power plants, and sells them for considerably less than its competitors.[244] While international companies offer some technologies that are not manufactured in China, Chinese firms produce a standard power plant at a highly competitive price that makes it an attractive option for many customers. Moreover, China has become the global leader in project financing for power, and offers highly competitive concessionary financing. As a result, China now dominates the international market for power plants of all types, but particularly coal and hydro plants (Figure 11). In India, for example, private power producers purchase mainly Chinese equipment, although the state-owned power producer still acquires Indian-made products mainly from joint ventures with European manufacturers.[245] India is just one example of the growth in China's customer base. The main competition for Chinese power coal-fired plants is not in the United States, so there is not a direct

[242] Claire Baldwin and John Ruwich, "Special Report: How Caterpillar Got Bulldozed in China," Reuters, January 23, 2014.

[243] Xiaomei Tan and Deborah Seligsohn, "Scaling Up Low-Carbon Technology Deployment: Lessons from China" (Washington, DC: World Resources Institute, 2010), http://pdf.wri.org/scaling_up_low_carbon_technology_deployment.pdf.

[244] Coal-fired power plants are described by their efficiency: in other words, what percentage of the coal's energy is captured and used to produce electric power. Conventional power plants have efficiency ratings of 32–37 percent, while super critical plants produce efficiencies of 37–40 percent. Ultra-supercritical reaches up above 45 percent efficiency. SourceWatch, "Coal Power Technologies" wiki page, last modified September 18, 2015, http://www.sourcewatch.org/index.php/Coal_power_technologies.

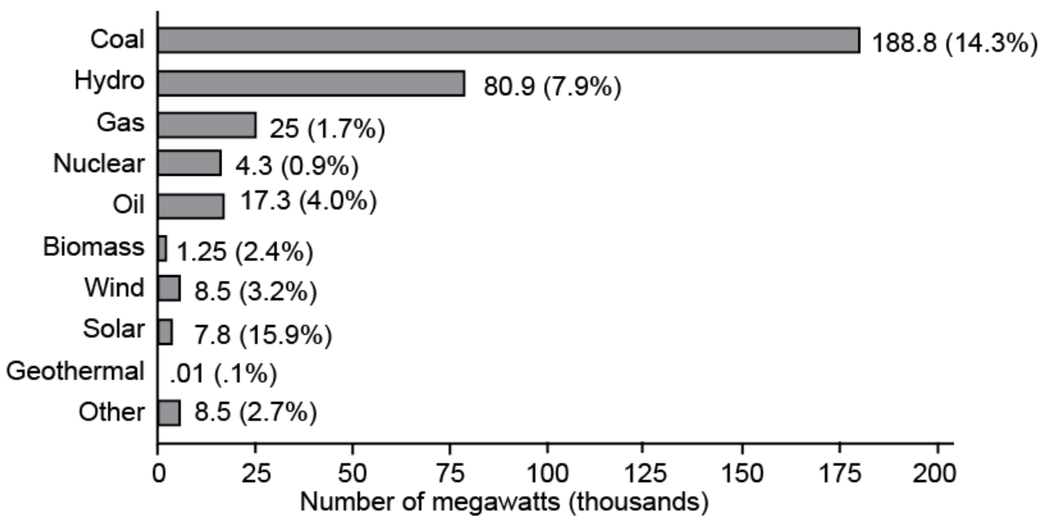
[245] P. Hannam, Z. Liao, S. Davis, and M. Oppenheimer, "Developing Country Finance in a Post-2020 Global Climate Agreement," *Nature Climate Change* 5 (November 2015): 983−87.

impact on the US trade position. The greater impact is indirect, as many countries weigh what power source they want to add to their electricity grid.

The low cost of Chinese coal-fired power plants competes with both renewables, where China is also a major player, and with natural gas, especially in the wake of the gas revolution in the United States. The United States is highly competitive in the production of gas turbines. Moreover, gas-fired power plants have the added attraction of being relatively fast to construct and low in carbon relative to coal, as well as not producing either sulfur dioxide or much particulate pollution (although they do produce high amounts of mono-nitrogen oxides.

China has been selling power plants internationally for a number of years, but this effort is being reinforced by President Xi Jinping's "One Belt, One Road" initiative. This grand scheme envisages a "New Silk Road Economic Belt" extending from China across Central Asia to Turkey, and a "Twenty-First Century Maritime Silk Road" linking China to Southeast and South Asia and Africa. The major emphasis of this plan is that Chinese companies should "go out" to seek new investment and trading opportunities.[246] While the plan ostensibly encourages outward investment, the major impact in the energy sector, according to the Eurasia Group's Erica Downs, has been a shift from seeking energy plays to seeking to sell major infrastructure projects. Premier Li Keqiang has specifically emphasized selling high-end capital goods, including power plants.[247]

Figure 11. Chinese involvement in power projects outside of China since 2000



Notes: Data includes plants that are in operation, under construction, and planned. Percentages in parentheses are Chinese involvement as a percentage of total projected world capacity.

Source: Based on data in supplementary information, Tables 3 and 4, P. Hannam, Z. Liao, S. Davis, and M. Oppenheimer, "Developing Country Finance in a Post-2020 Global Climate Agreement," *Nature Climate Change* 5 (November 2015): 983−87, DOI: 10.1038/NCLIMATE2731.

[246] The Economist Intelligence Unit, "Prospects and Challenges on China's 'One Belt, One Road': A Risk Assessment Report," 2015, http://www.eiu.com/public/thankyou_download.aspx?activity=download&campaignid=OneBeltOneRoad.
[247] Author interview with Erica Downs.

For developing countries, the growth of the Chinese power equipment industry has given them a wealth of options for the source and type of power they wish to add to their grids at a time when many of them still need to increase their supply of basic energy services. Some of these options, including for renewable and nuclear power from China, are low carbon. But the low cost and high quality of Chinese coal-fired power generation equipment and the price pressure this increased competition has had on the whole market means that coal-fired power plants are still an attractive option for many countries. A study of power plants planned and under construction by Phillip Hannam and several other scholars found that a number of countries, including India, Indonesia and Vietnam, are experiencing a shift from more diverse sources, including hydro and natural gas, to coal.[248] The purchase of a new plant often means locking in coal use for fifty years. This brings with it profound climate implications, as well as human health risks in the consuming countries.

Pollution Abatement

Beginning with the 11th FYP in 2006, the Chinese government became serious about its pollution abatement targets. For the first time, it established "hard" targets for two pollutants: chemical oxygen demand (COD), a measure of water pollution, and sulfur dioxide (SO_2), an air pollutant. It met its water goal in the 11th FYP and exceeded its SO_2 goal.[249] It then added goals in the 12th FYP for NO_x and ammonia nitrogen, one air and one water pollutant. Within the energy sector, the air pollutant targets so far have primarily addressed coal-fired power generation, but this is changing. The addition of a NO_x goal adds regulation to China's small number of gas-fired power plants. In addition, the increased stringency of these targets is now also affecting the oil and gas sectors by requiring upgrades of refineries, both for their own emissions and for the quality of the products they produce.

Chinese coal is relatively high in ash and contains what might be considered a medium level of sulfur, which must be removed through end-of-pipe technology.[250] Chinese power developers rely primarily on local suppliers for basic pollution abatement technologies, which include electrostatic precipitators, flue-gas desulfurization (FGD), and a variety of NO_x abatement options. The build-out of FGD capabilities during the 11th FYP was the largest demand spike ever seen globally.[251] Chinese power plant executives report that Chinese-made FGD equipment costs one-tenth of an international import, and they largely used these cheaper, domestically-produced technologies to

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[248] Hannam et al., "Developing Country Finance." Note that in some sense this is a hypothetical shift. These countries are all building new coal-fired power plants. Hannam et al.'s argument is that the mix of new power plants is more skewed toward coal than the existing mix of power generation in these countries and they suggest (although they do not actually have a causal story, just a powerful correlation) that this is due to inexpensive Chinese power plants.

[249] See Table 5 (pp. 74–75 in this report).

[250] Author interview with Weidong Wang, Lawrence Berkeley National Laboratory. September 10, 2015.

[251] This is a calculation based on the size of coal-fired generation capacity, where only the United States would be comparable. China installed virtually all of its FGD equipment during the 11th FYP, covering 86 percent of all its plants. Jeremy Schreifels, Yale Fu, and Elizabeth Wilson, "Sulfur Dioxide Control in China: Policy Evolution During the 10th and 11th Five-Year Plans and Lessons for the Future," *Energy Policy* 48, July 4, 2012. The United States has used a greater variety of methods to control SO2, including low sulfur coal, and only 58 percent of US plants today have scrubbers. Energy Information Administration, "Coal Plants Without Scrubbers Account for a Majority of US SO2 Emissions," *Today in Energy*, December 21, 2011.

meet the rising demand. While initially there was criticism from foreign firms that Chinese equipment was less efficient, the difference turned out to be a result of specifications, not quality. Once tighter air quality regulations were adopted in 2012, Chinese plants upgraded their equipment.[252]

As a result of its own build-out, China is now a leading competitor in conventional pollution abatement technology. Most of this technology is not new and there is very little IP involved. Chinese prices for such technology are now so far below competitors that China would appear to have a clear edge in developing country markets. While this looks like a loss for international competitors, including those from the United States, the reality is that most developing countries, including China, were buying very little of this equipment before China entered the market and drove down prices. If countries such as India and Indonesia upgraded their own facilities with low-cost pollution abatement equipment, the potential lives saved would be in the millions annually.

While most conventional pollutants can be addressed with off-the-shelf technology, Chinese planners are also interested in developing next-generation technologies. The 13th FYP (2016–2020) is expected to be the toughest yet in terms of both pollution and carbon targets.[253] The Chinese authorities are supporting the development of two alternative coal-fired power plant technologies: fluidized bed and IGCC. The IGCC technology also offers the possibility of integrating with CCS technology—methodologies for capturing carbon dioxide from flue gas and piping and storing it underground.

CCS is an added cost to power generation, so it is unlikely to be implemented unless there are mandatory and/or international carbon reduction commitments. However, China is pushing ahead with technology development and is now leading the world in the development of capture technologies, specifically through its GreenGen IGCC project.[254] The IGCC project also presents an option for more efficient coal use. Absent a requirement for carbon capture, it is not clear how often this option will be chosen. Conventional coal-fired power plants have become much more efficient at a much lower cost. The greater challenge for China is that it is not a world leader in turbine technology. The GreenGen project uses imported turbines for at least some of its functions.[255] Given the lack of traditional natural gas supplies, China had not invested as heavily in turbines as it has in coal boiler technologies and is now working to catch up.[256]

Organizations like the Thermal Power Research Institute in Xian clearly see potential in a carbon-constrained world for marketing CCS units not just in China but in other coal-dependent countries. While China is moving ahead rapidly with demonstration projects, this is actually an area where there is potential for fruitful bilateral cooperation with the United States. While the Chinese are

[252] Lijian Zhao, C. James, and D. Seligsohn, “China Adopts World-Class Pollutant Emissions Standards for Coal Power Plants,” World Resources Institute, June 15, 2012.
[253] Chuin-Wei Yap, “China’s Big Industry Braces for Five-Year Pain,” *Wall Street Journal* China Realtime blog, September 18, 2015.
[254] Shisen Xu, “Moving Forward with the Huaneng Greengen IGCC Demonstration,” Cornerstone, September 30, 2014; “Greengen Fact Sheet: Carbon Dioxide Capture and Storage Project,” *Carbon Capture & Sequestration Technologies @ MIT*, January 5, 2015.
[255] GreenGen plant site visit, Tianjin, China, October 2010.
[256] Gallagher, *The Globalization of Clean Energy Technology,* 146.

ahead on capture, the United States is more advanced on storage technologies.[257] The two countries have cooperated in this area for a number of years. Both are active in the Carbon Sequestration Leadership Forum, and one of the Clean Energy Research Centers, established in 2009, is dedicated to CCS research. Scaling this type of research up to larger demonstration projects would require greater funding.

Nuclear Technology

A major attraction of the Chinese nuclear industry, however, is technology. China began training large numbers of nuclear engineers in the 1950s for its nuclear weapons plan. Civilian nuclear power development followed at the beginning of the 1970s, but the first nuclear power plant proposal, the 310 MW domestically designed Qinshan 1 pressurized water reactor, was approved only in 1981. Construction took another decade, and it finally opened in 1991.[258]

At the same time, the Chinese nuclear power industry began seeking international partners and initiated the Daya Bay project in Guangdong Province in 1982. In 1985, the China National Nuclear Power Corporation (CNNC) signed a joint venture with China Light and Power Co. from Hong Kong, and in 1986, the joint venture company agreed to purchase power plant technology from Framatome (which later became Areva). Talks with Framatome had begun in 1978, but the 900 MW plant itself was not commissioned until 1994.[259]

This slow pace of nuclear power development continued. As of 2000, China had just Qinshan and two plants at Daya Bay in operation, and a decade later installed capacity reached just 10 GW, a goal that was originally set for 2000.[260] According to Liu Xinrong, former Vice President of the Second Research Design Institute of the Nuclear Industry, the focus during the 1990s was on "self-reliance and localization."[261] There were some additional international deals, including the purchase of two Candu units from Canada, which came on line in 2003.

The major turning point occurred in 2004 when the State Nuclear Power Technology Corporation (SNPTC), which had advocated for imported technology, won the argument with CNNC, which had pushed for the self-reliance model.[262] This led to an agreement in 2007 with Westinghouse Corp., which had been acquired by Toshiba Corp. of Japan a year earlier, for the purchase of four third generation AP1000 reactors and the ultimate transfer of the AP1000 technology to China.[263]

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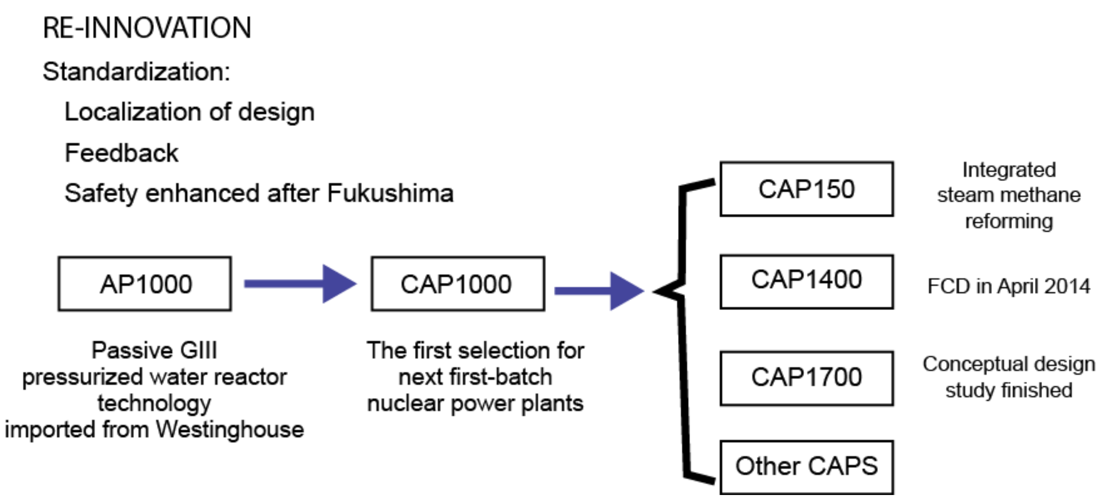
[257] Author interview with Sarah Forbes, US Department of Energy, August 30, 2015.
[258] IAEA Country Nuclear Power Profiles, 2013 Edition, "China (Updated 2003)," http://www-pub.iaea.org/MTCD/publications/PDF/CNPP2013_CD/countryprofiles/China/China.htm.
[259] Information on Daya Bay comes from the China Light and Power website, accessed January 26, 2016, and S. Charbonneau, "Framatome Contribution to Chinese NPP Development and Standardization," presented to the International Conference, Nuclear Option in Countries with Small and Medium Electricity Grid, Opatija, Croatia, 1996, http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/29/035/29035049.pdf.
[260] Liu Xinrong, "The Status and Trends of Nuclear Power Development in China," presentation, September 6, 2013.
[261] Personal knowledge from discussions as US Embassy energy officer in the early 1990s.
[262] World Nuclear Association, "Nuclear Power in China," updated January 6, 2016.
[263] Ibid. See also David Winning, "Westinghouse Seals China Deal; Four Nuclear Plants to Be Open by 2015, More Accords Seen," *Wall Street Journal*, July 25, 2007.

As of now, China is moving forward briskly in civilian nuclear technology development. A central plank of its strategy has been the 're-innovation' of foreign technology that is modified and re-branded as Chinese indigenous output. This is the case with the third-generation CAP1400, which is a modified version of the AP1000 pressurized water reactor to which China acquired full technology rights from Westinghouse in 2007 (Figure 12).

The Chinese nuclear industry is now building and marketing the CAP1400 domestically and globally. The first of these plants, the Hualong One, is currently under construction in Fuqing, Fujian. CNNC is actively seeking international markets with the goal of selling six to eight reactors by 2020. CNNC Vice President Li Xiaoming has stated that the company is actively seeking markets in Europe, North Africa, and Latin America, and that "new prospects" include Egypt, Saudi Arabia, and Sudan.[264] Generous state-backed export financing is available for these deals. While some of these countries might arouse nonproliferation concerns, China carefully abides by international nonproliferation protocols as a IAEA member, and its projects are subject to international inspection.

Table 6 shows all the international projects currently under consideration. Only the first plant, a conventional second generation plant in Pakistan, is actually under construction. With China yet to finish completion of its first third-generation plant that is based on technology transferred from Westinghouse, it is reported that prospective international buyers are skeptical of China's offerings.[265]

Figure 12. The 're-innovation' of China's nuclear reactor technology



Source: Lin Tian, "CAP1400 Design and Construction," PowerPoint presentation, June 27, 2013, slide 13, https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-06-24-06-28-TM-NPTD/14-snerdi.pdf.

[264] Lyu Chang, "Nuclear Reactor Exports on Cards," *China Daily*, June 17, 2015.
[265] Charlie Zhu and David Stanaway, "'Made in China' Nuclear Reactors a Tough Sell in Global Market," Reuters, March 6, 2015.

Table 6. Export sales and prospects for Chinese nuclear power plants

Country and project	Type	Estimated cost	Company	Construction start	Planned completion	Status, financing
Pakistan						
Chasma 3 & 4	CNP300	$2.37 billion	CNNC	March 6, 2013 (Chasma 3)	2016 for Chasma 3; 2017 for Chasma 4	Under construction, Chinese finance 82% of $1.9 billion
Karachi Coastal 1 & 2	Hualong One	$9.6 billion	CNNC	N/A	N/A	Planned, $6.5 billion vendor finance, maybe 82% China finance
Romania						
Cernavoda 3 & 4	Candu 6	€7.7 billion ($9.21 billion)	CGN	November 2013	N/A	Planned, to complete partially built units, Chinese finance
Argentina						
Atucha 3	Candu 6	$5.8 billion	CNNC	November 2015 (contract signed)[3]	N/A	Planned, with local involvement and $2 billion Chinese financing
Atucha 4 or other site	Hualong One	$7 billion	CNNC	November 2015 (contract signed)	N/A	Vendor financing envisaged
United Kingdom						
Bradwell	Hualong One		CGN	October 2015 (contract signed)	2025	Promised future opportunity
Turkey						
?	AP1000 or CAP1400		SNPTC	N/A	N/A	Exclusive negotiations involving Westinghouse

Sources: "Nuclear Power in China," World Nuclear Association, accessed January 8, 2016, http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/; "Chashma 3 Gets Its Dome," World Nuclear News, March 22, 2013, http://www.world-nuclear-news.org/NN-Chashma_3_gets_its_dome_220313a.html; "Romania Expresses Support for China's Role at Cernavoda," World Nuclear News, January 25, 2016, http://www.world-nuclear-news.org/NN-Romania-expresses-support-for-China-role-at-Cernavoda-25011601.html: "Nuclear Power in Argentina," World Nuclear Association, February 2016, http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx; "Hinkley Point Nuclear Agreement Reached," BBC News, October 21, 2015, http://www.bbc.com/news/business-34587650.

While Chinese nuclear exports are still in their infancy, the attractions are clear. If the Chinese succeed in beginning operations with Hualong One, it will be state-of-the-art, and reports are that it costs two-thirds of competing international models.[266] At the same time, international companies still see potential for contracts in China. Westinghouse CEO Daniel Roderick told Bloomberg News in December 2015 that he expects Westinghouse to be competitive against Chinese manufacturers in upcoming bids to construct nuclear power plants in China, pointing to an estimated need to build thirty AP1000 plants over the next decade. These could be either Hualong One or Westinghouse models. While Roderick expressed optimism, other commentators have pointed to delays in Westinghouse's current projects, as well as the cost differential.[267]

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[266] Tetsuya Abei, "State-Owned Enterprises Eye Overseas Power Projects," *Nikkei Asian Review*, January 5, 2016.
[267] Stephen Stapczynski et al., "Westinghouse Races China for $1 Trillion Nuclear Power Prize," *Bloomberg Business*, December 9, 2015.

The Chinese nuclear energy industry has among the most active R&D plans for fourth-generation nuclear power development, especially in terms of demonstration projects rather than the core science behind it. Tsinghua University's Institute of Nuclear and New Energy Technology originally developed a 10 MW demonstration facility on the outskirts of Beijing. Tsinghua signed a memorandum of understanding (MOU) with MIT in 2003 to share research.[268]

China also began construction in 2012 on a much larger 210 MW facility, still called a demonstration, in Shidaowan, Shandong Province, with an expected completion date of 2017.[269] This pebble-bed technology is still highly experimental, but if successful its modular design could enhance both safety and versatility.[270] China also has an MOU with South Africa to work on this design.[271] The US side does not have any fourth-generation demonstration facilities and its focus has been primarily on research.

With the largest market anywhere in the world for new nuclear power plants, China's nuclear industry has been able to negotiate excellent terms with foreign suppliers. China has increased the proportion of domestic IP with each successive generation of power plants, in part because of its negotiating position as a monopsony buyer and in part because of its heavy investment in nuclear engineering education. China has a long history of producing nuclear engineers that dates back to the 1950s. Starting in 2007, Chinese universities expanded these plans, adding five different nuclear specialties and expanding the number of students.[272] At the same time, nuclear engineering education has stagnated in the United States.

Hydropower

Chinese companies already lead the world in new hydropower installations and are very active in exporting of hydro projects, such as the Merowe Dam in the Sudan and the Mayitsone Dam in Burma. Hydro projects are an important part of the One Belt, One Road initiative and are precisely the type of projects the Chinese government wants to encourage in an economic slowdown. They use large amounts of Chinese equipment and raw materials and considerable Chinese labor. As of early 2014, China had been involved in 304 international dam projects.[273]

Smart Grid

The China Smart Grid Major Science and Technology Industrialization Project 12th FYP lists the full range of smart-grid related technologies as priorities for indigenous innovation. These include:

1. Renewable grid connections and electricity storage
2. Grid interconnection and long-distance transmission
3. Automation and network controls

[268] "MIT, Tsinghua Collaborate on Development of Pebble-bed Nuclear Reactor," *MIT News*, October 22, 2003.
[269] "Construction Progresses on China's High Temperature Pebble Bed Nuclear Reactor," *Next Big Future*, April 9, 2014.
[270] Christina Larson, "China Wants Nuclear Reactors, and Lots of Them." *Bloomberg Business*, February 21, 2013.
[271] Rod Adams, "Pebble Bed Reactor MOU Between China and South Africa," *Atomic Insights*, March 30, 2009.
[272] International Atomic Energy Agency (IAEA), "Human Resources for Nuclear Power Expansion," (undated, but a follow-up to a 2009 IAEA report), accessed September 20, 2015, https://www.iaea.org/sites/default/files/gc54inf-3-att5_en.pdf.
[273] Frauke Urban and Johan Nordensvard, "China Dams the World: The Environmental and Social Impacts of Chinese Dams," *E-International Relations*, January 30, 2014.

4. Smart metering
5. Demand-side response technologies
6. Electric vehicle charging and support

However, it does not appear that equal emphasis is being placed on all six areas. To understand Chinese thinking on smart grids, it is important to understand how they are viewed and defined in China. Grid interconnection and, to a lesser extent, automation and network controls in the list of priorities are the objects of most Chinese focus. These priorities align with China's efforts to improve the grids' physical infrastructure and ensuring system security and efficiency.[274] Priorities in Western countries are linked more to smart metering and demand-side management, but these issues receive much less attention from Chinese energy planners, even though they are addressed in the development plans.

The Chinese system continues to struggle with the integration of renewable energy into the grid. Part of the problem is institutional, such as rigid pricing systems and divisions between provinces. The biggest headaches are technical, especially managing fluctuations in supplies of renewables.[275] Variability comes in two forms: 1) longer-term (when the sun shines or the wind blows), and 2) shorter-term (changes in solar intensity or wind speed and direction). The former requires better grid management and better storage. The latter requires better technical integration of the grid. These areas provide opportunities for international cooperation, and there is a real need in particular for more work on cost-effective storage. Much of the assistance to date on shorter-term fluctuations has come from projects with German entities.[276] There is considerable potential, however, for cooperative work with US organizations in this area, and the September 2015 agreement between the National Renewable Energy Laboratory (NREL) and State Grid makes US–China cooperation more likely.[277] NREL and its Chinese partners, organized through the NDRC's Energy Research Institute, are currently implementing five projects on grid integration as well as four on standards and certification, in addition to several more policy-oriented projects. This is a considerable increase in technical cooperation, where NREL and its Chinese partners had previously completed one project each in grid integration and standards and certification.[278]

While demand-side management appears increasingly likely to be able to assist with China's energy efficiency efforts, relatively little has been applied in practice. As noted earlier, the major effort has been within-sector efficiencies in the 11th and 12th FYPs to shift the economy toward less energy-intensive and higher value-added activities, including both high-technology manufacturing and services. The current Chinese energy pricing structure does not enable retailers to incentivize time switching or otherwise foster demand-side change. This is a regulatory and institutional issue, not a technological constraint. Even if China were to use more of these types of technical grid management tools, it is unlikely to become a large market.

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[274] Author interview with Lingwei Zheng, China Energy Group, Lawrence Berkeley National Laboratory, September 10, 2015.
[275] Author interview with Joanna Lewis, Georgetown University, August 27, 2015.
[276] Author interview with Jonas Nahm.
[277] Samantha Page, "This US Lab Just Agreed to Help China Use Even More Renewable Energy," *Climate Progress*, September 18, 2015.
[278] NREL, "US-China Renewable Energy Partnership Projects," accessed January 25, 2016, http://www.nrel.gov/international/uscrep_projects.html.

Looking to the external market, China's clear comparative advantage is in long-distance, high-voltage transmission. China has installed more of such lines in recent years than any other country, with major advances in efficiency. As Chinese firms build power plants internationally, it can be expected that they will provide the transmission infrastructure as part of the package. China's advantage in these areas is that it can easily assemble a full package, including the power plant, pollution abatement, and transmission.

Electric Vehicles

New EVs are one of the seven priority areas highlighted by the SEI plan included in the 12th FYP. The effort actually got underway prior to the 12th FYP after Wan Gang became S&T minister in 2007. Wan, a former Audi executive, has been particularly focused on building up the Chinese automobile industry and chose EVs as the best choice. His logic is that other OECD countries already dominate the market for conventional vehicles and for hybrids. Moreover, Chinese companies have not been able to license hybrid technologies from Japanese firms.[279] Consequently, China's only choice is to leapfrog advanced competitors into the EV market.

MOST has made major use of the 863 applied research plan to fund initiatives in this area. On paper, the plan promotes comprehensive development, and uses the slogan "3 Vertical, 3 Horizontal" (三纵三横):

- Three vertical: hybrid cars, pure EVs, fuel cell vehicles
- Three horizontal: batteries, motors, control systems

Many of the targets of the 863 Plan are of the kind that Chinese groups use to meet targets, but do not actually show whether there is substantive progress, such as one for 3,000 new patents, without any evaluation of whether the patents are meaningful or important. But the overall goals are to:

- Reach an overall vehicle efficiency of 20km/liter (or 47 mpg) by 2020
- Use 10 percent of total electricity output in support of all electric vehicles
- Develop the EV industry in 30 cities
- Have available 400,000 charging points and 2,000 filling stations by 2015

These goals seem unlikely to be reached, however. The infrastructure gaps are the most obvious. As of 2014, the entire country had 723 filling stations (up from 76 in 2010), and the number of charging points had increased from a little more than 1,000 to 28,000.[280] The Chinese automobile industry also has not succeeded in producing the quality of lithium ion batteries originally sought.[281]

According to Columbia University Energy Institute's David Sandalow, this is the second effort by the Chinese government to jump-start the electric vehicle industry. The first effort in 2009 petered out, and Sandalow is skeptical that the latest effort will be any more successful. The largest structural issues are the proliferation of auto manufacturers in China and the need for cooperation from

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[279] Gallagher, *The Globalization of Clean Energy Technology,* 149.
[280] "Research and Markets: China Electric Vehicle Charging Station and Charging Pile Report 2015–2016," BusinessWire, March 23, 2015.
[281] Gallagher, *The Globalization of Clean Energy Technology,* 57.

State Grid.[282] An examination of the Chinese auto industry shows that repeated efforts to consolidate have failed.[283] With the proliferation of firms comes local protectionism.

At the same time, Sandalow said the need for grid company cooperation is much greater in China than would be the case in the United States because more than 50 percent of vehicles in the United States are parked overnight with access to an outlet. This is not the case in China. In general, this speaks to a larger problem of cross-ministerial cooperation and integration. The outlet access problem could also have been reduced if new buildings were required to install outlets in garages. Given the speed of urban construction in China, requiring the installation of outlets in new buildings would have expanded outlet access rapidly.

In sum, electric automobiles continue to be an area where the Chinese are experimenting. However, it does not seem likely that EV development will enable them to become dominant players in the world auto industry any time soon. The industry case study on electric vehicles later in the report provides additional information.

Wind

Chinese entities have made great strides in the wind sector and are widely regarded as being at world-class levels for technology and deployment.[284] As in other areas, the Chinese government's goal is to have all components designed locally. The targets in the Wind Power Technology Development 12th FYP address cutting-edge technologies, infrastructure, and other adjustments pertaining to grid connection issues. The goals in the planning process include:

1. Production of much larger turbines. China wants to mass produce 3–5 MW direct drive wind turbines and components, and to develop 7 MW turbines. The stretch goal is 10MW offshore turbines.
2. Development of better long-term wind resource data.
3. Development of national testing and certification systems (essentially an IP issue, since certification systems specify types of intellectual property).

Two additional goals to reduce the stress of the grid-connection issue are:

- Development of more non-grid wind for industrial use
- Development of direct industrial applications (industries generate own power so not reliant on the grid)

The general view in the wind industry is that because many components are large they tend to be built close to market. Because China has provided consistent government support and has a natural

[282] Author interview with David Sandalow, Columbia University, August 25, 2015.
[283] For example, see article by Norihiko Shirouzu (*Wall Street Journal*, February 5, 2009) that said China's auto industry was going to be reduced from its then-80 firms, and an article by Sumantra B. Barooah (*Auto Car Professional*, June 9, 2015) reporting that the government intended to cut back 20 firms from the current more than 100 manufacturers.
[284] Author interviews with Jonas Nahm and Joanna Lewis.

market, the wind industry has flourished, according to Kelly Gallagher.[285] Observers find that domestic deployment has been particularly critical for a successful wind industry.[286]

Chinese manufacturers have been successful in exporting wind components to both OECD and Asian regional markets.[287] At the same time, some manufacturers, in particular GE, Gamesa, and Vestas, have had some success in marketing wind turbines in China. Whether the foreign presence in China will expand or remain limited is the subject of considerable debate among analysts.[288]

Solar Power

While wind capacity in China developed initially in response to domestic demand and government policy, the solar industry began as a rural electrification policy, but blossomed when the industry spotted the export opportunity afforded by solar subsidy plans in some OECD nations.[289] What had become a singular focus on exports changed after the abrupt shrinking of international solar markets following the 2008 global financial crisis, but China continues to maintain a robust export trade in solar cells. This development has been on par with international producers, especially when calculated on a cost per kWh basis, but there has not been much new solar technology developed in China. The mass production cell business has been based on imported production lines. As Kelly Gallagher has pointed out, the industry continues to rely heavily on imported technology and IP from foreign research institutes.[290]

There are some indications in the Solar Energy Development 12th FYP, however, that the Chinese government would like to see more solar-related R&D taking place in China. The plan calls for the establishment of a national solar laboratory, but there have been few indications that this is currently underway. The Chinese government would also like to foster research into bringing solar costs down. Targets in both the solar and solar technology plans call for improving materials, reducing imported inputs, and bringing the price of solar cell technology and production equipment to international levels.

The plan comes with a lengthy slogan:

> One goal (large-scale generation and break-even cost with conventional power), two breakthroughs (scale of production and of technology application), three technologies (crystalline silicon cells, thin film, and new cell technology), and four directions (deployment of materials, devices, systems and equipment).

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285 Gallagher, *The Globalization of Clean Energy Technology.*

286 Priya Barua, Letha Tawney, and Lutz Weischer, "Delivering on the Clean Energy Economy: The Role of Policy in Developing Successful Domestic Solar and Wind Industries," World Resources Institute Working Paper, 2012, http://pdf. wri.org/delivering_clean_energy_economy.pdf.

287 Jing Cao and Felix Groba, "Chinese Renewable Energy Technology Exports: The Role of Policy, Innovation, and Markets," 2013, German Institute for Economic Research, https://www.diw.de/documents/publikationen/73/diw_01.c.414422.de/dp1263.pdf.

288 David Weston, "Question of the Week: The Future of China?" *Windpower Monthly,* April 20, 2015.

289 Cao and Groba, "Chinese Renewable Energy Technology Exports"; Gallagher, *The Globalization of Clean Energy Technology,* 63.

290 Gallagher, *The Globalization of Clean Energy Technology,* 64–65.

Despite this emphasis in the plan on replacing imports, the history of the Chinese solar industry would suggest this course of action is unlikely.

After the 2008 financial crisis, China's focus was on the deployment of large-scale and rooftop PV domestically and demonstration projects for new technologies.[291] Chinese solar deployment has been aided by a feed-in tariff. At the end of 2015, it was reported that NDRC planned to reduce the feed-in tariff by US $0.003 to US $0.02 per kWh. Given falling prices for equipment, this drop is not expected to slow down solar installation. Some analysts expect the change in pricing to encourage distributed and off grid solar power.[292]

The 12th FYP called for greater efforts to deploy solar thermal plants and the establishment of microgrids. There have been a number of solar deals with foreign firms announced in the past few years, but so far none have advanced very far. The latest deal is a 2014 joint venture between US company Brightsource and Shanghai Electric.[293] The two companies have said that they plan to build two 135 MW towers with molten salt storage, with the possibility of four additional units.[294] If the challenges of high capital costs and issues with storage can be resolved, many areas in northern and western China are well suited to solar thermal.

Microgrids have also gotten off to a slow start. The goal has been to foster more distributed generation, and the 12th FYP had a target for the establishment of 30 microgrids. While there are a few experimental microgrids currently in operation, the NEA did not issue guidelines for more widespread development until July 2015.[295] One of the challenges with microgrids and other related developments has been the entrenched bureaucracy of the grid companies, State Grid and Southern Grid, which operate as monopolies in their regions. There is hope that grid system reforms announced in April 2015 will ultimately produce a more conducive environment for distributed generation, but these reforms have yet to make much of an impact. The grid bureaucracy has proven extremely difficult to disentangle and overcome.[296] Changes in tariffs may help boost this part of the industry.

Solar energy is an area where US, international, and Chinese companies share considerable complementarities. Despite the intentions to focus on domestic supply articulated in Chinese planning documents, Chinese companies have been allowed considerable freedom to collaborate with international companies, purchase IP, and interact with foreign markets according to their own interests.

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[291] Ibid.
[292] Saurabh Majapatra, "China's Solar Tariff Cut Likely to Boost Off-grid Market," *Clean Technica*, December 30, 2015.
[293] "BrightSource and Shanghai Electric Partner to Deliver Huanghe's CSP Projects," BrightSource Energy, November 10, 2014, http://www.brightsourceenergy.com/brightsource-and-shanghai-electric-partner-to-deliver-huanghe%E2%80%99s-csp-projects#.V0PNqZMrLVo.
[294] Stephen Lacey, "Concentrating Solar Power Isn't Worth Much Without Storage, Say Leading Executives," *Greentech Solar*, September 16, 2015.
[295] Brian Publicover, "China to Start Developing Microgrid Demonstration Projects," *ReCharge*, July 23, 2015.
[296] Aibing Guo, "China to Break Electricity Distribution Monopoly Over Sales," *Bloomberg Business*, November 29, 2015.

International firms have continued to design new technologies and sell production lines to China. Moreover, the use of low-priced, mass-produced solar cells in the United States has also fostered an industry of solar fabricators and installers. While US manufacturers have found support for their concerns about Chinese subsidies from the US International Trade Commission, the industry overall is integrated with different parts of the business in different countries.[297]

Natural Gas

For decades China paid little attention to natural gas development. The general view was that China had few reserves, and thus the system was established without much attention to the potential needs or design of a natural gas industry. Petrochemicals in China rely primarily on goal gasification for feedstock. The oil majors, CNPC, Sinopec, and CNOOC, were established to focus on oil. Interest in natural gas has grown more recently, because of: 1) the potential to reduce air pollution in China's severely polluted cities; 2) a strong association with a higher quality of life; 2) plentiful international sources accessible by pipeline or tanker; and 4) the US shale revolution, which has opened the eyes of Chinese planners to the potential of exploiting unconventional gas from shale or tight gas and from coalmine and coalbed methane.

The Natural Gas 12th FYP calls for a broad-based effort to expand all types of gas exploitation:

- Conventional gas, although growth in this area is limited.
- Coalmine methane, which is critical for mine safety as well as supplying energy.
- LNG, with government plans calling for major expansion despite concerns about foreign dependence and terminal safety. Other than nuclear energy, this is one of the few places where safety shows up in the plans. Imports were 15 percent in 2010 and projected to reach 35 percent by 2015.
- Shale gas, where there are plans, but relatively little action so far.

The natural gas FYP lists a variety of technologies that it would like to produce indigenously, but when Chinese companies have attempted shale gas development, they have both partnered with international majors and employed oil service companies. If shale gas were to take off in China, international companies, including experienced US companies, would likely assume a leading role.

The Chinese majors have not shown much enthusiasm for shale gas development. In fact, both Sinopec and a Henan firm were fined in 2014 for failing to honor a commitment to develop shale resources.[298] At the same time, Shell has scaled back its collaboration with CNPC, ostensibly "because of geological challenges and the area's dense population." However, there have been rumors

[297] Steven Mufson, "US Imposes Tariffs on Chinese Solar Panels," *Washington Post*, May 17, 2012; Barua, Tawney, and Weischer, "Delivering on the Clean Energy Economy."

[298] Miller, "The CCP Central Committee's Leading Small Groups"; "中石化被罚 797 万 外媒：中国页岩气项目失去动力" [Sinopec Was Fined ￥7.97 Million; Foreign Media Commented that Chinese Shale Gas Projects Lost Motivation], Sina, October 6, 2014, http://finance.sina.com.cn/chanjing/cyxw/20141106/090020746896.shtml; Lucy Hornby, "China Levies First Fines for Slow Progress on Shale Gas," *Financial Times*, November 4, 2014.

that Shell was unhappy with the shale project for years.[299] The general view was that CNPC did not have the flexibility needed to manage a shale gas project.

The geological challenges, however, appear to be a real issue. As a team from Columbia University's Center for Global Energy Policy outlined in 2014, China's underground geology is quite complex, and the shale resources are in highly mountainous areas. This issue, combined with the fact that most information on the geology is proprietary and held by individual companies, makes shale development riskier and more costly than in the United States.[300] Developing shale gas in China turns out to be far more complicated than simply applying US technologies. David Sandalow has pointed out that the technologies, and even logistics support, need to be adapted to local conditions. Trucks, for example, need to be able to handle much more mountainous terrain.[301] While these technical challenges are undoubtedly surmountable with sufficient economic incentives and a willingness to engage experienced international firms on favorable terms, present incentives are insufficient.

One additional major issue is that CNPC owns the pipeline system. While the 12th Natural Gas FYP calls for 100 percent localization of pipeline construction, it does not address the uncertainty other potential developers face in shipping their gas.[302] While the Chinese government is well aware that the shale revolution in the United States has relied heavily on independent oil companies and not the majors, even in the wake of the Zhou Yongkang scandal there have been no real moves to break up the oil industry and make it more competitive.

Over the longer run, however, shale gas resources are likely to be developed in China. Experience in the oil exploration and development sector suggests that when the Chinese government wants to see more rapid action, there are also likely to be more opportunities for US and international firms. In the meantime, some of the pricing issues are likely to be resolved more quickly, encouraging other sources of gas, particularly imports. The fundamental diversification and air pollution drivers are still there.[303]

With increased gas use will come greater demand for gas turbines for electric power. This is an area where US and European firms are well ahead technologically. Beijing will shutter the last of its four coal-fired power plants in 2016, and it is expected that other eastern cities will follow suit as they endeavor to meet tough 2017 air quality targets.[304] While some coal will be replaced with renewables, energy planners used to 24/7 reliability are likely to turn to gas for a significant portion of coal replacement.

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299 Eduard Gismatullin, "Shell Trims China Shale Venture on Sichuan Population Challenges," *Bloomberg Business*, September 5, 2014.
300 David Sandalow, Jingchao Wu, Qing Yang, Anders Hove and Junda Lin, "Meeting China's Shale Gas Goals," September 2014, Center for Global Energy Policy, Columbia University, http://energypolicy.columbia.edu/sites/default/files/energy/China%20Shale%20Gas percent20Shale percent20Gas_WORKING%20DRAFT percent20DRAFT_Sept%2011 percent2011.pdf.
301 Author interview with David Sandalow.
302 Author interview with Erica Downs.
303 Ibid.
304 Feifei Shen, "Beijing to Shut All Major Coal Power Plants to Cut Pollution," *Bloomberg Business*, March 23, 2015.

Oil

Oil has always been an area where external investment is controlled and allowed only in select onshore areas and joint ventures offshore. There has been more willingness to import foreign technologies, however, especially for offshore development and onshore areas with difficult terrain. The Chinese majors, CNPC, Sinopec and CNOOC, are making a concerted effort to improve their offshore drilling. CNOOC has been exploring very deep offshore in the South China Sea on its own. All three Chinese oil companies have had stakes in various Brazilian projects, where the goals are not just to increase supply, but to jointly develop deep underwater technologies.[305] While leading US and international companies appear comfortably in the lead technologically at this point, the Chinese are certainly indicating more interest in entering this area.

Market Reform

Institutional and structural issues are much greater impediments to some of China's energy goals than technology, even though technology is often at the forefront of the development plans. The energy planning documents list a number of reforms that the Chinese government would like to see. It is worth noting that while some industrial structures have been remarkably tenacious, like the make-up of the oil and gas industry, others have witnessed considerable change, especially the break-up of the old power generation monopoly into generating companies after 2002. Meaningful reform can be expected to occur over time, but not all reforms will happen with equal speed or thoroughness.

Major areas cited for reform in state plans include:

- **Price reform:** The Chinese government has done a great deal to bring prices more in line with world market prices over the last decade. In fact, energy in China is expensive for industrial and commercial users, since the Chinese grid charges businesses more than households for electricity. However, pricing systems, except for coal, are not flexible. As evidenced by the current, overly high price of natural gas, the pricing system, with its bureaucracies and set formulas, can find itself out of sync with world markets.[306] While this pricing regime is expected to continue for the foreseeable future, the most likely area for immediate reform is retail electricity pricing. More bulk sales can be expected in the short term while more tiers and variation can be expected over the longer term to enable a better structuring of demand.
- **Natural monopolies:** The most obvious area of immediate reform is within the grid companies. Reforms have already been announced to separate transmission and distribution, but this process will be slow and cumbersome. State Grid is politically powerful, and Chinese planners will also want to ensure that reforms do not risk the steady supply of electricity to Chinese

[305] Author interview with William Norris, George Bush School of Government, Texas A&M University, September 5, 2015.

[306] China's natural gas prices at the "city gate" averaged US $13.40/MMBtu in 2013 and 2014 and were $11.40/MMBtu after April 2015, according to Sergey Paltsev and Danwei Zhang, "Natural Gas Pricing Reform in China: Getting Closer to a Market System?" MIT Joint Program on the Science and Policy of Global Change, Tsinghua-MIT China Energy and Climate Project, Report No. 282, July 2015. In November the "city gate" price was lowered by $0.11, for an average of $11.29 (Brian Spedele, "China Cuts Natural Gas Prices to Spur Demand," *Wall Street Journal*, November 18, 2015). This compares with US "city gate" prices of between $4.00 and $4.65 between May and October 2015 (http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm, accessed January 26, 2016). These prices reflect the fact that LNG prices in Asia are high, and gas in the United States is particularly plentiful. European prices tend to be in between the US and Asian prices. See DG Energy, *Quarterly Report on European Gas Markets* 7, No. 3, 3rd quarter 2014.

businesses and consumers. Another important dimension is that many parts of the gas business are run as monopolies, although planners do not seem to be focused reforming this aspect. Reforms that might help move forward gas development include allowing coal companies to participate in gas development and creating pipeline companies.

- **Oversupply of companies in some areas:** Planners are still concerned about the large number of coal mining companies and the proliferation of solar companies. The coal industry has undergone considerable consolidation in recent years, and this is expected to continue as coal demand falls. However, the solar industry is less controlled by the central government and is often more connected to local interests, so it is not clear how much influence central plans will have in curbing excessive numbers of firms.

Environmental Goals

Environmental goals now have a major impact on the energy policy environment. In 2007, "Energy Efficiency and Pollution Abatement" became a top-level national policy. Beginning with the 12th FYP in 2011, all energy-related plans have environmental targets. The issue of environmental clean-up was no longer seen as a separate goal to be left to the MEP, and energy planning has become a core aspect of making environmental improvements. One key strategy that affects every aspect of the energy industry is substituting cleaner fuels for coal. These include renewables, nuclear power, hydropower, and natural gas. Equally important are efforts to reduce air pollution emissions from fossil fuel sources, namely coal, oil, and natural gas.

Pollution abatement has so far mainly affected the power sector, while energy efficiency efforts have covered a much broader range of sectors. Starting with the 12th FYP and especially with new targets for overall ambient air pollution in the Beijing, Shanghai, and Pearl River Delta metropolitan regions coming into effect in 2017, regulating power alone will not be enough. All other sectors can be expected to feel growing pressure to improve.

This should lead to two critical changes over the next decade. The first is that petroleum refiners will need to engage in serious upgrades. Improving vehicle emissions requires a coordination of vehicle and fuel upgrades. Without cleaner fuel, pollution abatement equipment in vehicles will not function properly. Consequently, more stringent regulation of refiners will be critical to achieving pollution targets.

In theory, China's petroleum refiners have already been producing gasoline since 2013 at the China IV (Euro IV) standard, but there is a great deal of concern about insufficient enforcement of this standard.[307] Refiners are obliged to produce China IV for diesel by 2015, and then bring in China V (Euro V) standards for gasoline in 2017 and diesel in 2018.[308] The China IV standard brings China up to the standard the EU imposed in 2005−2006 (for diesel and gasoline), and the China V standard is the EU 2009−2011 standard. Europe currently has a Euro VI standard for gasoline,

[307] The Chinese standards for vehicle emissions are essentially the same as European standards, with I being the most basic, and VI the highest that is required in Europe today. The standards contain detailed specifications for both technology and performance.

[308] The International Council on Clean Transportation, "China V Gasoline and Diesel Fuel Quality Standards," January 2014.

which China has not announced plans to impose.[309] Improving vehicle emissions requires a coordinated effort between vehicle upgrades and fuel upgrades. Without cleaner fuel, pollution abatement equipment in vehicles fails to function properly. Consequently, more stringent regulation of refiners will be critical to achieving pollution targets.

The second needed change is a shift away from small-scale industrial use of coal. China is unusual in that almost half of its coal use is outside the power sector.[310] In most countries, coal is used primarily in power and then in a few other large-scale industrial sectors. It is very difficult to make pollution abatement cost effective for small users. The more common strategy is for these users to switch to other energy sources, including gas, electricity, and waste heat from power plants. Various Chinese cities are trying all of these approaches, and the effort to establish a natural gas price that is both low enough for consumers and high enough to encourage gas development is an important part of this switch.[311]

Finally, the energy sector needs to be concerned about more than just air pollution. A number of energy applications use large amounts of water, the most obvious being fracking and power generation. China already has a number of regulations to limit the amount of water used in cooling, from using dry cooling in the northern interior to locating nuclear power plants near the coast where they can use seawater. Both fracking and solar thermal power present new challenges. Solar thermal power typically uses large amounts of water for both cooling and cleaning, and these plants in China would be in the arid interior.[312] Fracking operations use a large quantity of water and affect water quality as well. Moreover, China's largest shale basin is in Sichuan, an area with considerable seismic activity.[313]

Chinese Urbanization Plans

The exodus of hundreds of millions of people from the Chinese countryside to urban areas in the past few decades represents one of the largest mass migrations in human history. This massive population redistribution has placed immense stress on the country's urban infrastructure, public services, and regulations. With tens of millions of people expected to join this exodus to the cities in the coming years, the Chinese authorities are having to devote growing political attention and economic resources to managing this challenging situation.

In March 2014, the State Council released a long-anticipated National New-type Urbanization Plan (see Table 7). The plan sets goals for addressing the challenges faced by China's rapid urbanization but also seeks to further increase the urbanization rate from 52.6 percent in 2012 to 60 percent by 2020. This would equate to an additional 100 million rural residents moving to urban areas.

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[309] "China: Light Duty: Emissions," http://transportpolicy.net/index.php?title=China:_Light-duty:_Emissions; "EU: Light Duty: Emissions," http://transportpolicy.net/index.php?title=EU:_Light-duty:_Emissions.
[310] Xiangkun Ren et al., "China's Policies for Addressing Climate Change and Efforts to Develop CCUS Technology," *Cornerstone* 1, No. 4, December 2013.
[311] Information in this paragraph comes from author fieldwork in several provinces, 2013–2015.
[312] China's Northwest is similar to the US Southwest in having abundant sun and little water. Nicole T. Carter and Richard J. Campbell, "Water Issues of Concentrating Solar Power (CSP) Electricity in the US Southwest," Congressional Research Service, June 8, 2009.
[313] Sandalow et al., "Meeting China's Shale Gas Goals."

Table 7. Targets of the National New-type Urbanization Plan

Indicator	**2012**	**2020**
Urbanization Level		
By residency	52.6%	~60%
By household registration (*hukou*)	35.3%	~45%
Basic Public Services		
Rate of migrant workers' children receiving public education	NA	≥99%
Urban unemployed, migrant workers, and new labor force entrants covered by free basic-professional-skills training plan	NA	≥95%
Urban residents covered by basic pension	66.9%	≥90%
Urban residents covered by basic medical insurance	95%	98%
Urban residents covered by affordable housing	12.5%	≥ 23%
Infrastructure		
Ratio of urban residents using public transport as a share of all motor vehicle transport in cities with population over 1 million	45% (2011)	60%
Access to urban public water supply	81.7%	90%
Access to urban sewage systems	87.3%	95%
Access to urban waste treatment facilities	84.8%	95%
Speed of urban household broadband Internet	4 mbps	≥ 50 mbps
Access to urban community service facilities	72.5%	100%
Resource and Environment		
Urban development land per capita	NA	≤ 100 m^2
Ratio of urban renewable energy consumption	8.7%	13%
Ratio of urban green buildings in new building construction	2%	50%
Ratio of green zones in urban areas	35.7%	38.9%
Ratio of prefecture-level cities with air quality meeting national standards	40.9%	60%

Source: "国家新型城镇化规划（2014–2020 年）" [National New-Type Urbanization Plan (2014–2020)], 新华社 [Xinhua], March 16, 2014, http://www.gov.cn/zhengce/2014-03/16/content_2640075.htm.

The Chinese authorities are deeply concerned that this large and concentrated population of rural immigrants, sometimes called "second-class citizens" in the media, could represent a serious source of social instability.[314] The plan calls for the "gradual elimination" of the chief cause of this second-class status: the household registration system, or "*hukou*" (户口). The *hukou* system, adopted in 1950s, ties people's access to public services such as healthcare and education to their

[314] "Moving On Up: The Government Unveils a New "People-Centered" Plan for Urbanization," *Economist*, March 22, 2014, http://www.economist.com/news/china/21599397-government-unveils-new-people-centred-plan-urbanisa-tion-moving-up.

residential status. In this system, a person's residential, or *hukou,* status, was defined by their place of birth and occupation. A clear distinction was made between rural and urban residency, and it was exceedingly difficult for rural residents to register as urban residents. This entrenched situation has made it challenging for rural migrants to gain equal access to the urban welfare system, even if they have resided in a particular city for an extended time.[315]

The reform of the *hukou* system, as detailed in the urbanization plan, will abolish the distinction between urban and rural, and grant rural migrants better access to urban public services. Such efforts include ensuring access to education for migrants' children, increasing healthcare insurance coverage and investment in basic healthcare resources, and establishing special training plans for rural workers.[316] While this reform appears to be an overhaul of the entire system, in practice, as experts have noted, it amounts to "a fairly small step."[317] On one hand, bigger cities, which migrants prefer, continue to maintain the principle of population control, and the barrier to obtaining urban status in such cities remains high. On the other hand, in small or middle-sized cities where local governments are unwilling or unable to invest more on social services, other settlement criteria have been created to replace the old *hukou* barriers.[318]

The plan also aims to optimize urban distribution layouts by nurturing cities of different sizes and establishing an urbanization development model that promotes high-density, public transit-oriented cities and green production and green consumption. Provision of public services such as education, health care, affordable housing, and employment is also a key focus of the plan. It calls for a comprehensive plan for the construction of schools, healthcare facilities, and cultural and sports venues based on population growth trends and distribution. It also advocates innovative mechanisms to supply public services, where government provision of public services will be higher and actual suppliers and methods will be diversified.

While the movement of 100 million rural residents to cities over the next five years is ambitious, it continues the urbanization rates experienced over the past decade. China's urbanization rate grew from 41.8 percent in 2004 to 53.7 percent by the end of 2014. This has meant approximately 16 million people per year relocating to urban areas.[319]

This planned expanded migration into the cities up to 2020 will cause new demands on China's infrastructure, energy supply, and other sectors. As part of the plan, the Chinese authorities will expand the existing rail and national highway network to cover all cities with populations greater than 200,000. The high-speed rail network will cover all cities with populations of more than 500,000. Real estate construction will receive a large boost from intensifying residential demand.

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[315] "China Reforms Hukou System to Improve Migrant Workers' Rights," *Guardian*, July 31, 2014, http://www.theguardian.com/world/2014/jul/31/china-reform-hukou-migrant-workers.

[316] "国家新型城镇化规划 (2014–2020 年)" [National New-Type Urbanization Plan (2014–2020)], 新华社 [Xinhua Agency], March 16, 2014, http://www.gov.cn/zhengce/2014-03/16/content_2640075.htm.

[317] Bingqin Li, "China's Hukou Reform a Small Step in the Right Direction," East Asia Forum, January 13, 2015, http://www.eastasiaforum.org/2015/01/13/chinas-hukou-reform-a-small-step-in-the-right-direction/.

[318] Ibid.

[319] Lin Xiaozhao, "中国每年城镇化人口相当于一个荷兰" [China Urbanized the Population of Holland Each Year], 新浪财经 [*Sina Finance*], November 18, 2014, http://finance.sina.com.cn/china/20141118/013820843692.shtml.

For example, one estimate shows that in 2011 15 million Chinese residents moved from rural to urban areas, and approximately 15–20 percent of the total urban population (35–46 million families) planned to buy homes within three months.[320]

Provincial and local governments have also drawn up urbanization plans for their regions. Sichuan provincial governor Wei Hong, for example, announced that Sichuan plans to promote this "new-type" urbanization by increasing investment on urbanization infrastructure by 20 percent to RMB 150 billion ($23.3 billion) in 2015. Through the Construction Plan of Ten Major Infrastructure Projects in Cities and Towns, the Sichuan provincial government and its Development and Reform Commission plan to invest heavily in local roads and bridges, flood control and drainage, sewage treatment, garbage disposal, water supply and conservation, heat and gas supply, ecological parks, and electric power and communication.[321] Similar projects will be implemented in many other provinces.

Energy demand will also rise sharply. Studies show that the average per capita energy and electricity consumption of Chinese urban citizens is 3.5 times and 3 times that of rural residents, respectively.[322] Moreover, for each percentage increase of the urbanization rate, Chinese national energy consumption increases 60–80 million tons of coal equivalent (TCE). Consequently, by 2020, new energy consumption is expected to exceed 360–480 million TCE.[323] Some Chinese experts, however, view this new urbanization as having minimal impact on China's near-term economic prospects but a more profound impact over the medium to long term. They argue that development of the "new urbanization" is a long process, as it takes time to construct city infrastructure and change consumption habits.[324]

China's continued urbanization will have a major long-term impact on income levels. In 2014, urban residents' incomes were almost three times as high as rural residents. Furthermore, since 2011, urban consumption accounted for almost 80 percent of China's total consumption and will account for an even greater share in the coming years.[325]

China's urbanization plans offer multiple opportunities for US interests. The major opportunities come from China's desire to make its cities and infrastructure more "eco-friendly." The underlying

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[320] Frank Holmes, "China's Urbanization is Driving Housing Demand and Car Sales," *Business Insider*, March 17, 2011, http://www.businessinsider.com/chinas-urbanization-is-driving-housing-demand-and-car-sales-2011-3.
[321] "魏宏：下深水解难题 促进四川城镇化持续健康发展" [Wei Hong: Solve the Big Problem and Facilitate the Sustained and Healthy Development of Sichuan's Urbanization], 人民网 [*People's Net*], January 20, 2015, http://www.sc.gov.cn/10462/10464/10797/2015/1/20/10324171.shtml.
[322] "新型城镇化对能源消费总量的影响及对策" [Impact of New-type Urbanization on Energy Consumption and Solutions," State Information Center of China, December 10, 2014, http://www.sic.gov.cn/News/82/3862.htm.
[323] Ran Yongping and Liu Zhiqiang, "新型城镇化，呼唤清洁能源" [New-type Urbanization Calls for Clean Energy], *人民网* [*People's Daily*], April 28, 2014 http://energy.people.com.cn/n/2014/0428/c71661-24948093.html. Wang Xiuqiang, "新型城镇化中的能源投资机会" [Energy Investment Opportunities in the New-type Urbanization], 新浪财经 [*Sina Finance*], March 19, 2014, http://finance.sina.com.cn/zl/energy/20140319/092218550013.shtml.
[324] Mao Mingjiang, "新型城镇化催生五大投资机遇" [New-type Urbanization Feeds Five Investment Opportunities], 中国证券网 [*China Securities*], March 31, 2014, http://news.cnstock.com/news/sns_yw/201403/2968813.htm.
[325] Mao Mingjiang, "New-type Urbanization Feeds 5 Investment Opportunities."

issue of this "eco-friendly" approach are concerns about energy consumption and the pollution associated with it. Energy consumption in China has already reached a high level compared to Japan, the United States, and India. Such massive energy consumption has become one of the biggest constraints to China's economic development and a top contributor to its polluted environment. As more urbanization will likely raise energy consumption, China strives for energy-efficient technologies and alternative energy sources.[326] Already, many US entities are taking advantage of this opportunity. For example, the US Secretaries of Commerce and Energy led a mission to China in April 2015 with the goal of promoting US smart city products and service exports to China. These include green buildings, building management, green data centers, carbon capture, utilization, and storage (CCUS), energy-efficient technologies, clean air and water technologies, waste treatment technologies, smart grids, and green transportation.[327] The United States and China are also working together to promote deployment of CCUS through a variety of bilateral and multilateral platforms, including the US–China Fossil Energy Protocol, the US–China Clean Energy Research Center, the US–China Climate Change Working Group, and the Carbon Sequestration Leadership Forum.[328]

Chinese regulations and investments point toward continued opportunities for US companies in these fields. As of 2014, the State Council mandated that any construction project the government invested in and any single building area over 20,000 m^2 must meet the green building standards of China's 3-Star Rating System.[329] China has also widely adapted the US Leadership in Energy and Environmental Design (LEED) certification with a current total of 196 LEED-certified and 596 LEED-registered projects in China.[330]

The Chinese government also began attracting private capital through joint ventures and wholly foreign owned enterprises in public infrastructure projects in April 2014.[331] One area is the market for power transmission and distribution. China is already the world's leading consumer of smart grid technologies, and is currently constructing smart grid operation and control systems and installing smart meters across the country. It is forecast that total investment in this area will reach $20 billion annually through 2020.[332]

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[326] Ran Yongping and Liu Zhiqiang, "新型城镇化，呼唤清洁能源" [New Urbanization Calls for Clean Energy], *People's Daily*, April 28, 2014, http://energy.people.com.cn/n/2014/0428/c71661-24948093.html.

[327] US Department of Energy, "Joint Department of Commerce and Department of Energy Smart Cities: Smart Growth Business Development Mission to China, April 12–17, 2015," 3, http://energy.gov/sites/prod/files/2014/12/f19/Dept%20of%20Commerce%20and%20Dept%20of%20Energy%20Joint%20China%20Mission%20Statement.pdf.

[328] US Department of Energy, "Joint Department of Commerce and Department of Energy Smart Cities," 5.

[329] Ministry of Housing and Urban-Rural Development, "绿色建筑行动方案" ["Green Building Action Plan"], March 2013, http://www.gov.cn/zwgk/2013-01/06/content_2305793.htm.

[330] US Department of Commerce, US Commercial Service, "Doing Business in China: 2014 Country Commercial Guide for US Companies," http://export.gov/china/build/groups/public/@eg_cn/documents/webcontent/eg_cn_078667.pdf.

[331] "Construction and Green Building," Export.gov, December 10, 2014, http://www.export.gov/china/doingbizinchina/leadingsectors/eg_cn_081022.asp.

[332] US Department of Energy, "Joint Department of Commerce and Department of Energy Smart Cities," 3–4.

Chinese Priorities for Technology Acquisitions from the United States and Foreign Countries

Current Chinese state plans for science, technology, industrial, energy, and defense development all call for the need to "strive for indigenous innovation." This is a phrase that first appeared in the MLP and is commonly associated with the promotion of original homegrown innovation. Another aspect of innovation that the Chinese plans highlight is combining foreign and local technology and knowledge in new ways as well as absorbing and upgrading imported technology.

The Chinese authorities have articulated a four-step approach to carry out this absorb and combine strategy of Introduce (引进), Digest (消化), Absorb (吸收), and Re-innovate (再创新), or 'IDAR':[333]

1. **Introduce:** This refers to the targeting and importation of foreign technologies and knowledge through a diverse range of channels, including legitimate and illicit means such as research, development, or production joint ventures, licensed transfers, and traditional and cyber-espionage.
2. **Digest:** Following the acquisition of foreign technology and knowledge, the next step is to digest and make sense of what has been collected and disseminate the findings. A network of several hundred defense and civilian S&T analytical organizations have been established to carry out this work. They are located across the defense and civilian S&T system.
3. **Assimilate:** Chinese authorities in both the defense and civilian industrial economies are investing heavily to build up state-of-the-art technology and engineering ecosystems to support efforts to assimilate and combine digested foreign technologies with local technologies. This includes the establishment of an extensive array of entities such as national engineering research centers, enterprise-based technology centers, state key laboratories, national technology transfer centers, and high-technology service centers. These facilities then engage in reverse engineering and other types of manufacturing processes to produce advanced copies of foreign models, or they 're-innovate' to combine Chinese and foreign components and platforms.
4. **Re-innovate:** The Chinese defense and civilian sectors have been able to 're-innovate' a growing list of advanced foreign technological products since the beginning of the twenty-first century. They include sophisticated fighter aircraft such as the Russian Su-27 (the Chinese version is known as the J-11B) and carrier-borne Su-33 (J-15) jets, high-speed trains based upon European and Japanese designs, and third-generation nuclear power stations that are improved versions of the US Westinghouse AP1000 reactor.

The IDAR strategy is most clearly set out in a 2006 supplementary document to the MLP that calls for encouraging the introduction of advanced foreign technology that can be digested and absorbed

[333] State Council, "Guidelines for the Medium- and Long-Term National Science and Technology Development Program (2006–2020)." See also Li Hong, Qian Li, and Chong Xinong, "试论技术引进与我国自主创新发展战略现代财经" [Discussion of China's Technology Introduction and Indigenous Innovation Policy], 现代财经[*Modern Finance and Economics*] No. 12 (2007): 67–70; and Qiao Weiguo and Chen Fang, "引进消化吸收再创新的政策体系与实施问题研究" [Research on the Policy System and Implementation of Technology Import, Absorption, and Re-Innovation], 政策研究 [*Science and Technology for Development*] No. 11 (2010).

for re-innovation. The document, titled the "Opinions to Encourage Technology Transfer and Innovation and Promote the Transformation of the Growth Mode in Foreign Trade," was issued by a group of eight powerful government economic, financial, and planning agencies that included the NDRC, MOF, and MOFCOM.[334]

The central goal of the "Opinions" is the building of a sophisticated advanced apparatus that brings in foreign technology transfers and allows for the effective absorption and re-innovation of products that China can effectively claim to be homegrown. A number of industrial sectors are highlighted that would benefit from this approach, including ICT, biotechnology, civilian aviation and aerospace, advanced materials, and machinery manufacturing.[335] Key initiatives that are emphasized include:

- Actively seeking bilateral and multilateral technical cooperation
- Improving and expanding open-source international information services that can be disseminated to local actors
- Encouraging and helping firms to go abroad to gain access to foreign R&D knowledge
- Attracting more multinational firms to set up R&D institutes and facilities in China

US and Foreign Technology Areas of High Priority for Chinese Acquisition

Following up on the "Opinions," the NDRC, MOF, and MOFCOM in 2007 issued the "Catalogue of Encouraged Technologies and Products for Import" (Import Catalogue) that provided a detailed list of key advanced technologies (先进技术) and important equipment (重要装备) along with resource-based products and raw materials (资源性产品、原材料) that the Chinese government is keen to acquire from overseas, especially from the United States. The catalogue also highlights key industries (重点行业) from which it seeks foreign technological assistance for development. In the initial 2007 Import Catalogue, the list contained 44 advanced technologies, 106 types of important equipment, and 66 key industries.[336]

In the most recent version of the Import Catalogue that was published in 2015, the list covers 492 items (see Appendix B). In the advanced technology category, there are a list of 243 technologies that cover a diverse range of areas, including agricultural production, environmental protection, energy saving, logistics, advanced manufacturing, transportation equipment such as high speed rail and electric and conventional automobile technologies, and energy-related technology including shale, gas, renewable, and coal liquefaction technologies. Not surprisingly, many of the technologies that are listed in this catalogue are included in the state S&T development plans such as

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[334] Ministry of Commerce, National Development and Reform Commission, Ministry of Science and Technology, Ministry of Finance, General Customs Administration, General Tax Administration, State Intellectual Property Office, and State Foreign Exchange Office, "Opinions to Encourage Technology Transfer and Innovation and Promote the Transformation of the Growth Mode in Foreign Trade," July 14, 2006, http://www.most.gov.cn/ztzl/gjzctx/ptzcyjxh/200802/t20080225_59303.htm.

[335] For an example of how one industry implemented this strategy, see "Railway Ministry: Our Country's Railway Is About How to Introduce, Absorb, and Re-Innovate," Xinhua, April 29, 2007, http://news.xinhuanet.com/politics/2007-04/29/content_6043932.htm.

[336] National Development and Reform Commission, "Catalogue of Encouraged Imports of Technologies," November 7, 2007.

the SEI and MLP. Technologies of a strategic nature with the potential for civil-military dual-use as well as defense applications include:

- Design and manufacturing technology for 10-petaflop high-performance computers[337]
- Aircraft engines, gas turbine blade and high-temperature precise casting technology
- Manufacturing technology for the production of large-scale integrated circuits
- Large sized transonic wind tunnel aerodynamic system design and manufacturing technology
- Manufacturing technology for high-performance aluminum and titanium alloy used for aerospace products
- High-powered laser manufacturing technology

There are 151 items contained in the category for important equipment. Technologies that have relevance for strategic and national security requirements include:

- Key parts and components used in aircraft manufacturing, especially engines, avionics systems, primary flight control systems, power supply systems, landing gear systems, fuel systems, auxiliary power units, and hydraulic systems
- Satellite manufacturing key components, in particular control and propulsion subsystems, measurement and control subsystems, power supply subsystems, digital transmission subsystems, navigation subsystems, repeater subsystems, antenna subsystems, and camera subsystems

Several of the 79 sectors that are listed in the category of technologies wanted for the development of key industries that have strategic and national security implications include:

- Advanced nuclear reactor construction and equipment manufacturing
- Large and medium-scale computers, 10-petaflop computers, portable microcomputers, high-end servers, large-scale analog simulation systems, and large size industrial computer controlled manufacturing
- Aviation engine development and manufacturing

Technology Acquisition Requirements in the Made in China 2025 Plan

An extensive number of technological areas are identified as important priorities for development in the Made in China 2025 plan. Although the plan makes fleeting reference to indigenous innovation (it is only mentioned twice), a key goal is to boost the technological and manufacturing capabilities of Chinese companies so that they can compete domestically and globally. This is to be achieved by upgrading the entire research, development, and production chain, with a particular emphasis on localizing the output of components and finished products. Another focus of the plan is to encourage Chinese outward investment, with an emphasis on countries linked to the One Belt, One Road initiative. These countries would serve as markets for Chinese goods. (See pages 169–171 for more discussion of this initiative.)

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[337] Petaflop refers to the ability of a computer to do one quadrillion floating point operations per second. China's Tianhe-2 supercomputer, which has the title of the world's fastest supercomputer, is a 33.86 petaflop machine.

Foreign technology acquisition will still be an important driver in the Made in China 2025 plan because China is still catching up in many of the areas highlighted for priority development. These include:

- Design and manufacturing of microchips
- Information and communications equipment, especially focused on high-end computing, high-speed Internet, advanced storage, 5G communications technology, processors and servers, and ultra-high-speed and large-capacity intelligent optical transmission technologies
- Processor systems and industrial software with a focus on information security and intelligent design and simulation
- High-end computer numerical control (CNC) equipment and robotics
- Aviation and space, especially in commercial narrow and wide-body airliners, helicopters, unmanned aerial vehicles, aircraft engines, next-generation launch and heavy launch space vehicles, satellites, air-space-ground broadband Internet systems, and long-term, persistent satellite remote sensing, communications, and navigation technologies
- Marine engineering equipment and hi-tech shipping, which includes deep sea exploration and marine industrial support equipment for the development of deep sea stations and large-scale floating structures
- New materials, in particular high-performance structural materials, functional polymers, inorganic nonmetals, and advanced composites. Additional priority will be given to disruptive materials such as super conductors, nanomaterials, graphene, and biological materials

The United States, and US companies more specifically, are among the front-runners in most, if not all, of these technologies and industries. For example, four of the top ten semiconductor companies investing in R&D in 2015 were US entities, including the top two, which were Intel and Qualcomm.[338]

Technology Acquisition Requirements in the Defense Domain

China's requirements for foreign defense technology and knowledge are likely to be as or more extensive than on the civilian side. These needs are extremely difficult to discern because the PLA and Chinese defense industry rarely openly disclose detailed requirements as their civilian counterparts have done with the Import Catalogue. However, there is considerable overlap between defense science, technology, and industrial development plans and their civilian versions, providing a useful starting point to understand Chinese technology requirements that are more strategic and dual-use in nature.

SASTIND director Xu Dazhe has noted that there is a close connection between the country's newly formulated Defense Science and Technology Industry 2025 Plan (国防科技工业2025) and the Made in China 2025 plan.[339] While little is known about the defense plan, areas of Made in China 2025 that include defense and dual-use priorities are the space, aviation, and shipbuilding sectors. There is speculation that the development of advanced military turbofan engines, which

[338] "IC Industry R&D Grew 0.5% Last Year, Says IC Insights," Electronics Weekly.com, January 22, 2016.
[339] "SASTIND Party Group Studies Spirit of Li Keqiang's Speech," 国家国防科技工业局 [State Administration for Science, Technology, and Industry for National Defense], June 16, 2015.

has long been an Achilles heel of the Chinese defense industry, is a key priority for both of these plans.[340]

The US Defense Department has pointed out that China's accelerating efforts to pursue civil-military integration (CMI) is providing an important conduit for the transfer of foreign advanced technologies for defense and dual-use. The Pentagon's annual report to Congress on Chinese military developments in particular points to the aviation and space industries as of growing concern to "increasing access to foreign technology from highly developed countries."[341] Critical technologies highlighted include key hot section technologies, materials such as carbon fiber and radar-absorbent material, multi-axis machine tools, avionics, data fusion and integration technologies, and engine/flight controls.[342]

Chinese military strategies and doctrines provide some broad strategic priorities for technological development that would require input from foreign sources. The 2015 Military Strategy, for example, highlights several areas that support an emphasis on informationized warfare:

- **Better utilization of information technology resources:** This would suggest development of technological capabilities that are able to better collect, analyze, and distribute large amounts of information.
- **Strengthening reconnaissance, early-warning, and command and control systems:** This would cover assets related to command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR), which would include development of secure tactical and strategic communications systems. Some examples would be data links; headquarters-level and operational-level command and control systems; electronic warfare capabilities such as jamming equipment, computer network operations, radar systems, airborne early warning; space-based sensor capabilities such as electro-optical and synthetic aperture radar satellites; and airborne sensors such as unmanned aerial vehicles and airborne signals intelligence aircraft.
- **Development of precision strike capabilities:** Key areas of focus would include short (less than 1,000 km), medium (1,000–3,000 km), intermediate (3,000–5,500 km), and intercontinental range (greater than 5,500 km) ballistic missile-related technologies such as propulsion and guidance systems; land-, air-, and sea-launched cruise and anti-ship cruise missile technologies such as inertial guidance, satellite guidance, and terrain contour matching technologies; ground attack munitions; and hypersonic weapons-related technologies.

The United States is a leading target of Chinese acquisition efforts because its defense and technology companies possess much of the world's most advanced defense and dual-use capabilities. Long-standing US sanctions and export controls against China prevent trade in militarily sensitive

[340] "SASTIND Confirms 'Defense Industry 2025' Plan," 上海证券报 [Shanghai Securities News], June 19, 2015.
[341] Office of the US Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2015*, April 2015, 16, http://www.defense.gov/Portals/1/Documents/pubs/2015_China_Military_Power_Report.pdf.
[342] Hot section technologies are components and technologies that comprise the hot sections of engines, most notably combustors and turbines. The Chinese aviation industry has encountered enormous difficulties in the successful development and production of aircraft engine hot sections, especially in areas such as turbine blades.

technologies and products, so China's main avenue to gain access to these assets is through espionage, both conventional and cyber.[343] According to a *Washington Post* article on a confidential assessment by the US Defense Science Board in 2013, foreign hackers had gained access to designs of more than two dozen major US weapons systems. This included plans for the PAC-3 Patriot missile system, Terminal High Altitude Area Defense (THAAD), Aegis ballistic missile system, F-35 joint strike fighter, F/A-18 fighter jet, V-22 Osprey, S-70 Black Hawk helicopter, and the US Navy's Littoral Combat Ship.[344]

While the Defense Science Board apparently did not accuse China of stealing the designs, many other US government agencies and US cybersecurity firms have been far less reticent to identify China as the primary culprit in cyber-espionage. The *Washington Post* also reported that a classified 2013 US national intelligence estimate (a consensus assessment of the US intelligence community) concluded that the United States was being subjected to a massive cyber-espionage campaign that was threatening the country's competitiveness and security. China was reportedly the most aggressive transgressor. Industries that came under Chinese attention included the energy, finance, IT, aerospace and automotive sectors.[345] In February 2013, the independent information security firm Mandiant released a report showing that an arm of the PLA systematically infiltrated 141 companies in over 20 major industries, including 115 US companies. These attacks began in 2006, and largely included companies in industries listed under China's SEI initiative.[346]

The Chinese authorities categorically deny that they engage in cyber-espionage activities and point out that they are also victims of cyber-theft. Although US President Barack Obama and Chinese President Xi Jinping agreed in September 2015 to halt commercial cyber-espionage activities against each other, China would lose an invaluable mechanism to advance its military and broader strategic technology capabilities were it to halt such operations.[347]

How Can the United States Better Protect Against Illegal Chinese Technology Acquisition?

The United States should redouble its efforts to deny China access to strategic technologies, both to safeguard its technological edge and also to impose costs on China. China has proven adept at pursuing a fast-follower strategy of acquisition, buying or stealing technology and the underlying intellectual property from both the United States and Russia. Efforts to deny China easy access to US military technology and intellectual property will, at the least, drive up the cost in terms of time and effort that China is forced to expend to acquire it. In other cases, such efforts may force

[343] The United States imposed sanctions on the export of militarily sensitive technologies to China in 1989 to punish the Chinese government for its crackdown on civilian protesters in Beijing. The sanctions regime has been tightened in subsequent years because of US concerns over China's security policies and posture, especially over issues such as cross-strait relations. For a detailed history, see Hugo Meijer, *Trading with the Enemy: The Making of US Export Control Policy Toward the People's Republic of China* (Oxford: Oxford University Press, 2016).
[344] Ellen Nakashima, "Confidential Report Lists US Weapons System Designs Compromised by Chinese Cyberspies," *Washington Post*, May 27, 2013.
[345] Ellen Nakashima, "US Said to Be Target of Massive Cyber-Espionage Campaign," *Washington Post*, February 10, 2013.
[346] Office of the United States Trade Representative, "2013 Special 301 Report," May 2013, 33, https://ustr.gov/sites/default/files/05012013%202013%20Special%20301%20Report percent202013 percent20Special percent20301 percent20Report.pdf.
[347] According to testimony by National Security Agency Director Adm. Michael Rogers to the Senate Armed Services Committee in April 2016, China was still targeting and exploiting US government, defense industry, academic, and private computer computers. See http://www.armed-services.senate.gov/imo/media/doc/Rogers_04-05-16.pdf.

China to seek less capable substitutes to US technology. In still other cases, the United States and its allies may be able to deny China access to critical technologies.

Such efforts should include both improved information security and updated technology transfer restrictions. Information security forms the first line of defense for US technology, and far too often China has been able to steal critical information because of poor information security practices. Information security measures in both government and private industry should be strengthened. Industrial espionage on the scale that China has been conducting cannot and should not be isolated from the overall Sino-American relationship. US leaders must make it clear that the continuation of such activities, whether actively abetted or passively tolerated by the Chinese government, will have a tangible negative impact on the US–China relationship. The United States may have to take measures that will trigger Chinese retaliation. Absent such action, however, it is doubtful that the Chinese defense S&T sector will forgo the considerable benefits that accrue to it from stealing US technology.

Given the vital importance of information security and cybersecurity for the United States and China, the issue requires the attention and engagement of the highest levels of the two countries' leadership. One recommendation is that the presidents of both countries should be actively engaged in meeting with each other to address concerns and find ways to forge robust and enforceable bilateral agreements to curb the most dangerous and egregious practices, not unlike the nuclear arms control treaties that were worked out in the 1960s and 1970s.

Technology transfer restrictions also need to be updated, both to reflect the current international technology market and to maximize their effectiveness. Moreover, it is in the national interest of the United States for the government and private industry to work cooperatively to develop best practices and share threat information. To be effective, however, such measures should prioritize those technologies that are likely to provide the greatest battlefield edge in the future. In the defense and national security realm, this would include space and cyber capabilities, unmanned systems, high-speed propulsion, advanced aeronautics, autonomous systems, electromagnetic rail guns, and directed-energy systems.

PART II

IMPLICATIONS FOR US NATIONAL SECURITY AND ECONOMIC COMPETITIVENESS

A. IMPLICATIONS FOR US NATIONAL SECURITY

This section of the report undertakes a diagnostic net assessment of US strengths and weaknesses as compared with Chinese strengths and weaknesses, together with their economic, political, and military underpinnings. It argues that China has exploited a series of favorable asymmetries in its competition with the United States. It concludes by suggesting how the United States might exploit some of its enduring advantages to preserve US superiority in the Western Pacific and beyond.

US Strengths

The United States possesses a series of enduring strengths that affect its national security, including those provided by its strategic geography, economic strength, society, military power, and alliances and partnerships. All too often, however, the United States has failed to exploit these strengths to the extent it could or should. It has focused instead on how others can leverage their strengths against US weaknesses rather than on how the United States can best use its strengths to exploit the weaknesses of competitors.

Geography

As an insular power, the United States has enjoyed security from military attack throughout much of its history. With friendly powers to the north and south and the Atlantic and Pacific oceans to either side, the United States has not had to worry about the threat of invasion since the War of 1812.

The development and deployment of nuclear weapons coupled with long-range delivery means—first bombers and then ballistic missiles—changed that equation, allowing adversaries to strike the United States from afar. Today, the United States is vulnerable to Russian and Chinese nuclear-armed intercontinental ballistic missiles (ICBMs), and in the near future will be vulnerable to North Korean ICBMs as well. China may also develop conventional long-range strike systems. In addition, the advent of cyber weaponry allows adversaries to strike the US homeland. Finally, as the September 11, 2001, terrorist attacks vividly demonstrated, non-state actors possess the ability to inflict a large number of casualties on the United States.

Even in the face of such developments, the US geostrategic position remains an enduring strength. Threats to the homeland, although real and growing, remain relatively low due to the security provided by the Atlantic and Pacific oceans and friendly neighbors to the north and south.

The Economy

The United States possesses great economic strength as well. It has the world’s largest economy and is also the world leader in innovation. US economic growth provides resources for defense and national security. When the economy is growing, it becomes politically easier to afford both national security and social spending. Conversely, when economic growth is sluggish, the trade-off between guns and butter is sharpened. Moreover, technology developed by the civilian economy has benefited US national security, for example, the way the automotive, shipbuilding, and aircraft industries were harnessed for military production during World War II or, more recently, the way that developments in information technology originating in the civilian economy benefit the military today.

The fact that the United States has long been the world leader in innovation also benefits US national security. In many cases, the US government has benefited from innovation that originated in the private sector. However, government policies have enabled US defense scientific and technological innovation in a number of notable cases. The space program in the 1960s and 1970s and the Strategic Defense Initiative in the 1980s both produced new militarily useful technologies far beyond the initial goals of the programs. Defense Department grants for 6.1 basic research in universities and support for university-affiliated research centers have also provided much-needed funding to spur innovation. In addition, the Defense Advanced Research Projects Agency (DARPA) has served a unique role in developing innovative technology for national security.

At least since the early Cold War, the United States has relied upon technological innovation to provide an edge against quantitatively superior adversaries.[348] During much of the Cold War, the United States both relied upon its nuclear arsenal to offset numerically superior Soviet conventional forces, as well as the qualitative superiority of US nuclear weapons to offset the Soviet nuclear arsenal. Near the end of the Cold War, the United States relied upon conventional precision strike systems, advanced sensors, and command and control systems to counter the Soviet Union's ground and air forces. These transitions serve as antecedents to the current "Third Offset Strategy," which seeks to use innovation to offset the growing capabilities of competitors such as China.

Society

American society is the source of other advantages that benefit US national security. For example, the United States possesses demographic strengths that are nearly unique in the world. US fertility rates are among the highest in the developed world. Although the United States is aging, it is doing so to a lesser extent and more slowly than other major powers. As a result, the economic and fiscal costs of aging will be significantly lower for the United States than its competitors. As Nicholas Eberstadt has commented, "if the American moment passes, or US power in other ways declines, it won't be because of demography."[349]

Immigration also serves as a source of American advantage. The US population includes emigrants from literally every country in the world who speak the full breadth of the world's languages. More importantly, it is one of only a handful of states that has the ability to bring new emigrants to its shores, weave them into the fabric of the society, and make them full members of that society within an individual's lifetime.

America's role as a beacon of immigration has benefited US national defense for the better part of a century, to include the refugees from Nazi Germany and Fascist Italy who played a key role in the US atomic bomb program, the German scientists who helped build the US missile and space industry, or immigrants from South and East Asia who play central roles in Silicon Valley today. Ironically, it was an emigrant from the United States, Qian Xuesen, who became the father of the Chinese missile and space plans.[350]

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[348] See, for example, Thomas G. Mahnken, *Technology and the American Way of War Since 1945* (New York: Columbia University Press, 2008).
[349] Nicholas Eberstadt, "Born in the USA: America's Demographic Exceptionalism," *The American Interest* 2, No. 5, 52–58.
[350] Iris Chang, *Thread of the Silkworm* (New York: Basic Books, 1995).

Military Strength

The United States possesses considerable military strength as well. It spends more on defense than the next seven states combined, an investment that has yielded the most capable military in the world. The United States possesses the world's largest nuclear force, with a deployed inventory of approximately 1,900 strategic nuclear weapons: 450 ICBMs with 450 warheads, 288 SLBMs with 1,152 warheads, and 60 bombers with 300 warheads.[351] It is also only one of only two countries in the world (the other being Russia) to possess a nuclear triad.

The United States also possesses the world's most capable army, with nearly a decade and a half of recent combat experience in Iraq and Afghanistan. It is a force that is proficient in combined-arms warfare and is highly networked. The United States also possesses the world's most capable navy, a force that is globally deployed and capable of projecting power rapidly. It is also unique in possessing a truly global air force.

The United States has been able to exploit space effectively for intelligence, surveillance, and reconnaissance (ISR); communications; and precision navigation and timing. The US space capability has multiplied the effectiveness of US ground, sea, and air forces, networking them together and increasing their situational awareness. The United States is also the world leader in exploiting the cyber dimension to support military operations.

Since the end of World War II, the US military has been based upon forward-deployed forces in Europe and Asia (and, since the 1980s, the Middle East), backed up by power projection from the United States. The US military is unique in possessing a truly global force posture, with forces deployed worldwide supported by bases and other facilities located on every inhabited continent, linked together by a global sea and air transportation network.

Alliances and Partnerships

The allies of the United States are another considerable strength. These include the members of the North Atlantic Treaty Organization in North America and Europe as well as Japan, Australia, South Korea, the Philippines, and Thailand in the Pacific. US allies include some of the most prosperous and militarily capable states in the world. Beyond formal allies, the United States also has friendly relationships with a number of key states in the Asia-Pacific region, including India and Vietnam.

Allies provide a number of advantages to the United States. In some cases, they provide military capabilities additive to those of the United States. For example, Australian forces have fought side-by-side with US armed forces in every war that the United States has fought in the last century, beginning with World War I. In other cases, allies provide capabilities that are in demand but in short supply in the US armed forces. For example, the Japan Maritime Self-Defense Force maintains anti-submarine warfare and mine countermeasures (MCM) forces that help make up for the limited capacity of the US armed forces in these areas. Cooperative defense programs with allies help increase interoperability with allies and gives the United States access to allied science and technology. Access to allied bases and facilities also allows the United States to forward-deploy forces closer to the scene of potential crises and conflicts, reducing response times and wear-and-tear on forces. In a number of cases, allies bear much of the cost of these facilities.

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[351] International Institute for Strategic Studies, *The Military Balance* (Abingdon, UK: Routledge, 2015), 40.

US Weaknesses

Although the United States possesses considerable strengths, it is not without weaknesses, which in many cases derive from aspects of its strengths. For example, whereas its insularity has provided territorial security for most of the United States, it is far from its territorial possessions, allies, and interests in the Western Pacific. Such a geographic reality has long been a concern of US planners. During the 1920s and 1930s, for example, considerable US Army and Navy planning had to contend with the imperative of defending the Philippines, then a US territory, from attack by Japan, a more proximate power.[352] Because the United States was ultimately unsuccessful in deterring a Japanese attack on the Philippines and preventing the Imperial Japanese Army from conquering it, it was forced to launch a multi-year campaign to liberate the islands at great cost.

Today, the United States faces the need to deter coercion of its allies and friends in the Western Pacific, including Japan, the Philippines, and Taiwan. It also faces growing threats to US territory in the region, including Guam. In an era in which US forward bases and forces are increasingly vulnerable, the importance of long-distance power projection will increase.

Similarly, although the United States possesses the world's largest economy, it is a mature economy characterized by low growth rates. This limits the amount of resources available for defense. Moreover, debt servicing and social spending continue to claim an increasing share of US government spending, further limiting what is available for defense. In addition, the United States faces decreasing buying power for its defense dollar as personnel and hardware costs continue to rise.

The American way of war also contains weaknesses. For example, it relies upon a relatively small number of fixed forward bases, on both US and allied territory. The ability of the United States to project power over great distances is also dependent upon the use of space assets for ISR; communication; weather; and precision, navigation, and timing. Should the United States be denied access to those bases, or should they become unusable, projecting power would be considerably more difficult. Similarly, denying US forces the ability to use space assets would complicate military operations, notwithstanding the fact that the US military is attempting to reduce its reliance on space.

Finally, although on balance America's allies represent a considerable strength, they could also create vulnerabilities. Although the United States and its allies have shared interests, they are not identical. As a result, allies could entrap the United States in local conflicts. For example, some fear that US security assurances to the Philippines give Manila incentives to behave more belligerently toward China than would otherwise be the case.[353]

Chinese Strengths

China has a number of noteworthy strengths. One flows from China's strategic geography. Traditionally, China has been able to use its continental size to its strategic advantage. In other words, China has been able to follow a strategy of defense-in-depth. Although historically most of the

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[352] Edward S. Miller, *War Plan ORANGE: The US Strategy to Defeat Japan, 1897–1945* (Annapolis, MD: Naval Institute Press, 1991); Louis Morton, "War Plan ORANGE: Evolution of a Strategy," *World Politics* 11, No. 2 (January 1959).
[353] This is an argument put forward by Chinese analysts. See "Emboldened Manila May Upset US Rebalancing to Asia," Xinhua, April 28, 2014.

threats to China have come from the land, since the end of the Cold War, China has enjoyed peaceful land borders and has resolved almost all of its land territorial disputes with its neighbors with the sole exception of India. This has allowed the Chinese leadership to concentrate their attention to the expansion and modernization of the PLA Navy and Air Force, which traditionally lacked the resources and organizational prestige of the army.

The ability of the CCP to exert control over the Chinese population has traditionally been a strength, albeit one that preoccupies the CCP leadership. Moreover, the need to control the population imposes considerable costs, especially the need to maintain an extremely large and costly internal security apparatus. The official Chinese internal security budget overtook the official defense budget in size in 2011.[354] Along with this control, the authoritarian nature of the Chinese political system allows the leadership to engage in the effective mobilization of resources and capabilities across the country if required.

The greatest source of strength has been the remarkable growth of the Chinese economy over the past 35 years. Annual GDP growth has been near double digits and the Chinese economy is now the second largest in the world. The growing prosperity and sophistication of the Chinese economy has supported rapid growth in the defense budget, which has increased by an annual average of around 10 percent over the past 25 years.[355]

The rapid modernization of the Chinese defense economy over the past two decades has turned one of its biggest strategic weaknesses into an emerging strength. China's defense economy has been enjoying a remarkable renaissance in its fortunes since the turn of the twenty-first century. Driven by leadership concerns about mounting challenges to the country's external security environment and rapid advances in the global technological order, investment into research, development, and acquisition has soared. Greater efforts are being made to acquire and absorb foreign technologies, and the existing defense innovation system is being remade.

This has resulted in significant improvements in technological, economic, and industrial performance. Defense corporations are posting record annual profits and the armaments R&D pipeline is bulging. The aviation sector, for example, is simultaneously engaged in the development or production of more than half a dozen combat and transport aircraft, while the shipbuilding industry has at least four active nuclear and conventional submarine programs along with research, development, and construction of aircraft carriers, destroyers, and numerous other surface warships. The PLA Navy is estimated to have laid down, launched, or commissioned more than 60 ships and smaller craft in 2014 alone, with the same number expected in 2015.[356] The space industry is also pursuing highly ambitious across-the-board development, including manned, lunar, anti-satellite, and satellite projects.[357]

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[354] "Internal Security Tops Military in China Spending," *Wall Street Journal*, March 5, 2011.

[355] For details of Chinese annual military expenditures for this period, see Stockholm International Peace Research Institute, *Military Expenditure Database*, http://www.sipri.org/research/armaments/milex/milex_database.

[356] US Office of Naval Intelligence, *The PLA Navy: New Missions and Capabilities for the 21st Century*, April 2015, 13.

[357] For an in-depth look at the Chinese space industry, see Kevin Pollpeter, Eric Anderson, Jordan Wilson, and Fan Yang, "China Dream, Space Dream: China's Progress in Space Technologies and Implications for the United States," report prepared for the US-China Economic and Security Review Commission, February 2015, http://origin.www.uscc.gov/sites/default/files/Research/China%20Dream%20Space%20Dream_Report.pdf.

A number of key factors have played instrumental roles behind the improving performance of the Chinese defense economy. They include high-level leadership support, a well-defined long-term vision backed up with detailed development plans, a shift from technology-push to demand-led innovation, the growing role of defense corporations, the nurturing of a defense innovation system and overhaul of the R&D apparatus, and efforts to promote the integration of the civilian and defense economies.

Top Leadership Support

High-level and sustained support and guidance from the political and military leadership elites is essential in the Chinese defense economy's ability to carry out innovation activities. Leadership backing and intervention has been vital in addressing entrenched bureaucratic fragmentation, institutional compartmentalization, and chronic project management problems that cause prolonged delays, decision-making paralysis, and cost overruns. Without outside leadership involvement, it is likely that many achievements of the defense economy would not have happened, especially the turnaround in the defense economy since the end of the 1990s.[358]

The central leadership's direct and continuing involvement and oversight in the operations of the defense economy and of critical projects is essential. This is often done through the establishment of leadership small groups and special committees. The committed involvement of the country's top leaders is also critical, and the defense economy has been fortunate that Xi Jinping has taken an active interest in defense issues. Xi has paid particular attention to the development of China's defense and overall innovation capabilities, as demonstrated by his intensive engagement in defense and S&T matters. Between November 2012 when Xi assumed power and the end of 2014, Chinese media reported that he took part in 21 events related to military and defense science, technology, and industrial issues. This included 17 inspection visits to defense facilities and his appearance in four major defense-related meetings. By comparison, Xi's predecessor Hu Jintao visited just a handful of defense facilities during the same period of his tenure.[359]

Activities that signaled Xi's interest in defense S&T issues include:

- **Inspection of the *Liaoning* aircraft carrier and J-15 carrier fighter plant, Liaoning Province, September 2013:** Within his first year as CMC chairman, Xi made a high-profile visit to tour the *Liaoning* aircraft carrier in Dalian and to inspect the progress of the J-15 fighter aircraft at Shenyang Aircraft Corporation.[360] This was a clear demonstration of Xi's keen interest in the development of China's naval airpower capabilities.
- **Tour of National University of Defense Technology, Changsha, Hunan, November 2013:** Xi has emphasized on his military visits that the defense S&T establishment's duty is to serve the needs of war-fighters. He noted during an inspection to the National University of Defense Technology, the military's leading high-technology R&D establishment, that the work

[358] Tai Ming Cheung, "The Chinese Defense Economy's Long March from Imitation to Innovation," *Journal of Strategic Studies* 34, No. 3 (2011): 325–54.
[359] This information is based on a careful review of Chinese media reporting during this period.
[360] "Xi Jinping Investigates Liaoning Military Industrial Enterprises," SASTIND website, September 6, 2013, www.sastind.gov.cn/n112/n117/c8439/content.htm.

of defense scientists and engineers should be "closely linked with real combat and army service." This fits with Xi's calls to the PLA to strengthen its preparations for "military struggle," which means enhancing combat readiness.[361]

- **Politburo study session on military innovation, Beijing, August 2014:** Xi chaired a study session of the full Politburo that was devoted to the examination of global trends in military innovation. Xi pointed out that a global revolution in military S&T affairs is currently taking place "at a speed so fast, in a scope so wide, at a level so deep, and with an impact so great that it has been rarely seen since the end of World War Two." Xi said this represented both a challenge and opportunity, which required China's defense establishment "to vigorously promote military innovation."[362]
- **Keynote speech at the All-Army Armament Conference, Beijing, December 2014:** With the leaderships of the PLA's armament apparatus and defense industry in attendance, Xi affirmed the "historical achievement" of the PLA's weapons development, and urged accelerating the pace of construction. He emphasized the importance of "unifying thinking" and "gathering consensus," which may have been hints of policy differences over the Third Plenum reform issues.[363]

Shifting the Defense Economy from Technology-Push to Demand-Pull

Major organizational reforms in the late 1990s allowed the PLA to gain primacy in guiding defense S&T R&D. Previously, the institutional interests of the state-owned defense industry overwhelmingly drove armaments development, while the PLA's requirements were secondary. Before the 1990s, the PLA had little option but to accept the output of the defense economy. As the quality of indigenous equipment steadily declined, the PLA became increasingly reluctant to procure these arms and began to look overseas for weapons in the 1990s, especially from Russia. This practice faded in the 2000s with the improvement in the quality of its domestic weapons.

A key reason behind this improvement is the role of the GAD, which is responsible for ensuring that military end-user needs are being served. To ensure that defense companies are in compliance with its requirements, the GAD has created incentive structures and monitoring mechanisms. First, it has imposed tougher competitive and evaluation procedures in the development and procurement of weapons systems. Second, the GAD has been willing to withhold or postpone orders for equipment that do not meet its requirements.

The Central Role of Defense Conglomerates

The rise of China's ten major state-owned defense corporations since the beginning of the twenty-first century has had a major impact in shifting the center of gravity for research, development,

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[361] "Xi Jinping Reviews Officials and Soldiers from National University of Defense Technology," Xinhua, http://news.xinhuanet.com/politics/2013-11/06/c_118036424.htm.

[362] "Xi Jinping Addresses Politburo 17th Collective Study Session, Emphasizes Need to Accurately Grasp New Trends in the World's Military Development, Advance with the Times to Vigorously Promote Military Innovation," Xinhua, August 30, 2014.

[363] Tang Xiuying and Zong Zhaodun, "Xi Jinping Attends PLA Armament Work Conference, Emphasizes Quickening the Building of an Armament System Commensurate with the Requirements of Performing Missions, Providing Strong Material and Technological Support for the Fulfillment of the Strong Army Dream," *China Military Industry News*, December 6, 2014.

and innovation from research academies and universities towards enterprises. These conglomerates, which each have between 100 to more than 200 subsidiaries, have sought to transform themselves from loss-making quasi-state bureaucracies to more market-driven enterprises. They have been allowed to reduce the size of their workforces, and shed heavy debt burdens, and given access to new sources of investment, especially from the capital markets.[364]

Combined with a strong pickup in defense and civilian orders, these companies have become highly profitable since the mid to late 2000s. Around two-thirds of the defense industry's annual revenue comes from civilian operations, such as automobiles and white goods.[365]

The aviation, space/missile, defense electronics, and naval sectors have been the chief beneficiaries of this rising tide of defense procurement, while the ordnance industry has enjoyed considerable success from sales of civilian products such as motor vehicles. These corporations are now engaged in an ambitious expansion strategy to become global arms and strategic technology champions.

Construction of a Defense Innovation System and R&D Base

The Chinese defense innovation system, and especially its R&D component, has been undergoing a significant overhaul and expansion to meet growing demand for its services from the PLA and as part of a larger development of the national innovation system. The development of a robust defense R&D system is a top priority in defense S&T development plans such as the MLDP, which emphasizes a number of key goals. A top priority is the shifting of ownership and funding of key portions of the state-controlled defense R&D apparatus to the country's defense conglomerates. The primary goals of this reform include: 1) reducing the dependence on state funding of the R&D apparatus; 2) increasing the amount of investment that firms devote to R&D, especially in applied and commercial development; and 3) speeding up the exploitation and commercialization of proprietary R&D output.[366]

Another high-level priority is the development of an extensive defense laboratory system to pave the way for long-term technological breakthroughs. Around 90 laboratories belonging to both the defense industry and PLA have so far been established. It will take some time before these research outfits are able to conduct high-quality R&D because they lack experienced and top-rated scientific personnel.[367]

Civil-Military Integration

Intensifying efforts since the early 2000s to forge close linkages between the civilian and defense economies have allowed the defense industry to gain access to more advanced and more globalized civilian sectors. This has led to the development of some modest functional and geographical pockets of civil-military activity since the early to mid-2000s. The electronics, IT, high-technology, and automotive sectors have been in the vanguard.

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[364] Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy* (Ithaca, NY: Cornell University Press, 2009), chap. 4.
[365] Cheung, *Fortifying China*, chap. 5.
[366] Ibid.
[367] "Enhance Innovation Capability for Sustainable Development," *China Defense Science, Technology, and Industry Journal* (August 2009): 17–19.

Another area of growing CMI activity is the competitive opening up of the defense research, development, and acquisition system to the private sector. Until a few years ago, this was the exclusive preserve of the ten state-owned conglomerates that monopolized the aviation, space and missile, ordnance, nuclear, electronics, and shipbuilding sectors. More than 500 private firms have so far received licenses that allow them to bid for contracts by mid-2013.[368] It is likely, however, that the overwhelming flow of business still goes to the established state giants, which have deep-seated connections in a non-transparent and under-regulated system.

The use of capital markets to fund the development and production of weapons projects is the third area in which CMI initiatives are being pursued. This has potentially the most significant near- and longer-term impact on innovation. While defense companies have been allowed to list subsidiaries on stock markets since the 1990s, this was limited to their non-defense operations. This changed in 2013 when SASTIND permitted firms to issue share placements using military assets as securitization.

China Shipbuilding Industry Corporation (CSIC) became the first defense firm to undertake a private share placement in September 2013 and raised RMB 8.5 billion ($1.3 billion) from 10 unidentified Chinese parties to acquire production facilities to manufacture warships. Military assets that CSIC used as collateral in the transaction included warships and landing craft. CSIC explained that the funds would "satisfy the development and manufacture of a new generation of weapons and equipment," adding that, "we need urgent large-scale technological improvements and need to expand our financing channels."[369] Dalian Shipyard is one of the CSIC facilities slated to receive proceeds from the 'share placement.'

The aviation industry, in the form of monopoly giant Aviation Industries Corporation of China (AVIC), has been the most active in tapping the financial markets with several of the most important entities in its defense portfolio conducting share placements.[370] They include Chengdu Aviation Corporation, which produces the PLA Air Force's J-10 fighter aircraft and is developing the J-20, China's first ever stealth fighter; AVIC Precision Machinery Corporation, which undertakes precision manufacturing; and AVIC's engine operations, which is responsible for jet engine development and production. After raising more than $2 billion for its engine business, AVIC is integrating all of its engine facilities into a single consolidated entity with the hope that this integration will finally allow the company able to overcome its long struggle to build its own advanced turbofan engines.[371]

The high level of state commitment to the defense economy shows few signs of weakening, despite the noticeable slowing of growth in the national economy in the past couple of years. For defense R&D, the investment in national S&T activities is a useful proxy indicator of political support and the trajectory in growth rates in the S&T sector. China's R&D expenditure in 2014 is estimated to

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[368] Bi Jingjing and Ren Tianzuo, chief eds., *China Civil-Military Integration Development Report 2014* [中国军民融合发展报告 2014 年] (Beijing: National Defense University Press, 2014), 82.
[369] "China Turns to Stock Market to Fund Navy," *Financial Times*, September 11, 2013.
[370] "Sichuan Chengfei to Buy AVIC's Military Assets for $2.5 Billion," Reuters, May 19, 2014.
[371] "AVIC May Reorganize Its Engine Business, Higher National Priority," *Huanqiu Wang*, October 9, 2015.

have reached RMB 1.34 trillion ($208.4 billion), which is around 2.2 percent of GDP and a sizeable jump from the 2013 spending of RMB 1.19 trillion ($185 billion).[372] However, it is not known how much was spent on defense-related activities. The Chinese authorities have set a target in the MLP for S&T spending to reach 2.5 percent of GDP by 2020, which would mean even higher rates in budget growth for the next few years.

Chinese Weaknesses

China also faces a wide range of weaknesses that stand in the way to its efforts to become a global power. Three in particular flow from China's strategic geography as a continental power. First, although China has enjoyed peaceful continental borders since the end of the Cold War, that peace cannot be guaranteed into the future. Tension between China and India, including friction over territorial disputes along the Sino-Indian border, is on the rise. Similarly, relations between China and Vietnam are strained. In addition, Chinese strategists are concerned about the potential for instability in Central Asia. As well, the currently cordial relations between Beijing and Moscow cannot be guaranteed over the long term. Should China face a hostile power or disorder on its borders, it would face a sharper trade-off between investing in land power, on the one hand, and air and space power on the other.

Second, China is increasingly dependent upon sea lanes of communication (SLOCs) that it is unable to control. Sea-borne commerce is vital to Chinese prosperity, and China is increasingly dependent upon imports of food and raw materials for its well-being. Although China's leadership recognizes this vulnerability and is according defense of SLOCs a higher priority, Beijing lacks the ability to safeguard China's access to resources. The PLA Navy is not strong enough to protect those SLOCs, nor is it likely to be strong enough to do so in the foreseeable future.

Third, although the vast majority of China's population is made up of Han Chinese, the existence of large groups of non-Chinese minorities, particularly on China's periphery, is a point of concern for the Chinese leadership. China's three largest provinces, Xinjiang, Tibet, and Inner Mongolia, all have large non-Chinese populations, and separatism is a major concern for Beijing.

The Chinese economy could turn into a weakness as well. Although the economy has been a source of great strength in recent decades, there is justifiable concern about the sustainability of the Chinese economic model. The CCP leadership has recognized the need to move from an export-led model of growth to one dependent on domestic consumption. In making such a move, however, the CCP leadership is gambling that an increasingly prosperous Chinese population will still be willing to accept an authoritarian political system.

Beyond the political implications of these shifts, there are reasons to question whether the Chinese economy will be able to continue to deliver as it has in the past. As China's economy matures and shifts from export-led to consumption-led growth, lower growth rates are to be expected. Reduced Chinese economic growth would, in turn, limit the overall pool of resources available to the PLA. Whereas the CCP leadership has not had to trade guns for butter in recent years, it may have to make such trade-offs in the future. Several related trends will likely further erode the buying power of the Chinese military. First, personnel costs have risen and will likely continue to rise to ensure that the PLA can recruit and retain the skilled manpower required to operate and maintain modern

[372] "China's R&D Spending Up 10 Percent in 2014," *Global Times*, November 23, 2015.

weaponry. Second, as with other modern militaries, the costs of defense S&T, as well as acquiring and maintaining hardware, will increase.

Finally, China lacks allies. The friends that it does have, such as Pakistan and North Korea, are often problematic. Pakistani territory has at times provided a safe haven for jihadist groups, including those active in western China. China's relations with North Korea under Kim Jong-Un have been especially strained as Pyongyang has ignored Beijing's entreaties to curb its nuclear weapons development. While China and Russia have forged steadily closer ties in the post–Cold War era, especially in the military and arms trade domain, a lingering and deep distrust remains an obstacle to further development of these ties.

Although Chinese investment in military modernization has yielded substantial new capabilities, the PLA retains a number of weaknesses, including in the areas of organization and human capital, combat capabilities, and the defense industry.[373] The principal constraints and weaknesses that the Chinese defense economy faces at present stem from its historical foundations and the uncertain efforts to overcome the corrosive legacy of its difficult history.[374] The institutional and normative foundations and workings of the Chinese defense industry were copied from the former Soviet Union's command defense economy and continue to exert a powerful influence to the present day. The PLA and defense industrial regulatory authorities are seeking to replace this outdated top-down administrative management model with a more competitive and indirect regulatory regime, but there are strong vested interests that do not want to see any major changes.[375]

Monopolies

One of the biggest hurdles that PLA and civilian defense acquisition specialists point out is the defense industry's monopoly structure. Little competition exists to win major weapons systems and defense equipment because China's six defense industrial sectors are closed to outside competition and dominated by a select handful of state-owned defense corporations. Contracts are typically awarded to these corporations through single sourcing mechanisms. Competitive bidding and tendering only takes place for non-combat support equipment, such as logistics supplies.[376]

An effort in 1999 to inject more competition by splitting corporations that monopolized their sectors did little to curb monopolistic practices because the new firms focused on different areas of business in their domains, and there was little direct rivalry. These powerful defense firms have subsequently sought to reverse this effort at "de-monopolization" by finding ways to remerge or collaborate. In 2008, the aviation industry made the first, and so far only, successful challenge by reconsolidating its two post-1999 entities into a single monopoly structure.[377] There have been

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[373] Michael S. Chase, Jeffrey Engstrom, Tai Ming Cheung, Kristen A. Gunness, Scott Warren Harold, Susan Puska, and Samuel K. Berkowitz, *China's Incomplete Military Transformation: Assessing the Weaknesses of the People's Liberation Army* (Santa Monica, CA: RAND Corporation, 2015).

[374] Ibid. In particular, see chapter 6.

[375] Tai Ming Cheung, "An Uncertain Transition: Regulatory Reform and Industrial Innovation in China's Defense Research, Development, and Acquisition System," in *Forging China's Military Might*, ed. Tai Ming Cheung (Baltimore, MD: Johns Hopkins University Press, 2014).

[376] Ibid.

[377] Lin Zuoming, "The Path of AVIC's Strategic Evolution," *China Aviation News*, April 17, 2012.

occasional reports that the space and shipbuilding sectors might also seek to re-establish a single holding company arrangement.[378]

Bureaucratic Fragmentation

A second serious weakness that has seriously handicapped the effectiveness of Chinese defense economy is its bureaucratic fragmentation. This is a common characteristic of the Chinese organizational system but is especially virulent within the large and unwieldy defense sector.[379] A key feature of the Soviet approach to defense industrialization that China imported was a highly stratified structure and process. There was strict separation between the defense and civilian sectors as well as between defense contractors and military end-users, compartmentalization between the conventional defense and strategic weapons sectors as well as among the different conventional defense industrial subsectors, and division between R&D entities and production units. Key reasons for this excessive compartmentalization include an obsessive desire for secrecy and the powerful influence of the deeply ingrained Chinese model of vertical functional systems (*tiao tiao,* 条条) that encouraged large-scale industries like those in the defense and supporting heavy industrial sectors to become independent fiefdoms.[380]

This severe structural compartmentalization is a major obstacle to the development of innovative and advanced weapons capabilities because it requires consensus-based decision-making that is carried out through extensive negotiations, bargaining, and exchanges. This management by committee is cumbersome, risk-adverse, and results in a lack of strong ownership that is critical to ensure that projects are able to succeed the thicket of bureaucratic red tape and cut-throat competition for funding.

This entrenched bureaucratic fragmentation is a prominent feature of the armament management system. Although the GAD is one of the PLA's four general headquarters departments with a seat on the CMC, it is only responsible for managing the armament needs of the ground forces, People's Armed Police, select space plans, and the militia.[381] The navy, air force, and Second Artillery have their own armament bureaucracies, and competition is fierce for budgetary resources to support projects favored by each of these services. The compartmentalized structure serves to intensify parochial interests and undermines efforts to promote joint undertakings. Coordination gaps and bureaucratic rivalry are also problematic between the GAD and the General Staff Department (GSD) and General Logistics Department (GLD) in areas such as policy planning, resource allocations, and drafting of longer-term development plans.[382] The reorganization of the PLA headquarters departments at the end of 2015 and their incorporation into an expanded Central Military Commission was intended to address the problem of bureaucratic fragmentation.

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[378] Interview with Chinese space industry expert, Beijing, November 2015.

[379] Kenneth Lieberthal and Michel Oksenberg, *Policy Making in China: Leaders, Structures, and Processes* (Princeton, NJ: Princeton University Press, 1988), 35–42. See also Kenneth Lieberthal and David Lampton, eds., *Bureaucracy, Politics, and Decision Making in Post-Mao China* (Berkeley: University of California Press, 1992) and David Lampton, ed., *Policy Implementation in Post-Mao China* (Berkeley: University of California Press, 1987).

[380] Cheung, *Fortifying China*.

[381] Mao Guohui, ed., *Introduction to the Military Armament Legal System* (Beijing: National Defense Industry Press, 2012), 46.

[382] Ibid., 45.

The research, design, and acquisition (RDA) system also suffers from compartmentalization along many segments of the RDA process. Responsibilities for R&D, testing, procurement, production and maintenance are in the hands of different units, and under-institutionalization has meant that linkages among these entities tend to be ad hoc in nature with major gaps in oversight, reporting, and information sharing.[383] The fragmented nature of the RDA process may help to explain why Hu Jintao was apparently caught by surprise by the first publicized test-flight of the J-20 fighter aircraft that occurred during the visit of US Defense Secretary Robert Gates in January 2011.[384]

Weak Management Mechanisms

A third major weakness is that the PLA continues to rely on outdated administrative tools to manage projects with defense contractors in the absence of the establishment of an effective contract management system. The PLA did implement the use of contracts on a trial basis in the late 1980s with the introduction of a contract responsibility system.[385] These contracts are administrative in nature, however, and have little legal standing because of a lack of a developed legal framework within the defense industry. Consequently, contracts are vague and do not define contractual obligations or critical performance issues such as quality, pricing, or schedules.[386]

Moreover, the PLA acquisition apparatus is woefully backward in many other management approaches and tools compared to its counterparts in the United States and other advanced military powers. It has yet to adopt total life-cycle management methods, for example, and many internal management information systems are on stand-alone networks that prevent effective communications and coordination.[387] One analyst said that this often meant that the only way for project teams to exchange information was through paper transactions, which is cumbersome, slow, and restricts the ability to share information.[388]

Outdated Pricing Regime

A fourth serious weakness is the lack of a transparent pricing system for weapons and other military equipment, representing a lack of trust between the PLA and the defense industry. The existing armament pricing framework is based on a 'cost-plus' model that dates to the planning economy, in which contractors are allowed 5 percent profit margins on top of actual costs.[389] This model has a number of drawbacks that hold back efficiency and innovation. One is that contractors are incentivized to push up costs as this would also drive up profits. Another problem is that contractors are not rewarded with finding ways to lower costs such as through more streamlined management or more cost-effective designs or manufacturing techniques. Contracts rarely have performance incentives, which discourages risk-taking or any willingness to adopt innovative approaches. Yet

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[383] See Liu Hanrong and Wang Baoshun, eds., *National Defense Scientific Research Test Project Management* (Beijing: National Defense Industry Press, 2009).
[384] John Pomfret, "Chinese Army Tests Jet During Gates Visit," *Washington Post*, January 12, 2011; Elizabeth Bumiller and Michael Wines, "Chinese Army Test Jet as Gates Visits," *New York Times,* January 12, 2011.
[385] Cheung, *Fortifying China*, 83–85.
[386] Chase et al., *China's Incomplete Military Transformation*.
[387] Life-cycle management refers to the implementation, management, and oversight of all activities associated with the development, production, fielding, sustainment, and disposal of a system across its life cycle.
[388] Interview with PLA analyst, Beijing, November 2011.
[389] Mao Guohui, *Introduction to the Military Armament Legal System*, 158–59.

another issue is that contractors are dissuaded from making major investments in new technological capabilities or processes because of the low profit margin.[390]

To address this long-standing problem, the PLA, MOF, and NDRC held a high-level meeting on armament pricing reform in 2009 that concluded that the outdated pricing system had seriously restricted weapons development and innovation.[391] A number of reform proposals were put forward: 1) provide incentives to contain costs; 2) switch from accounting procedures that focus on ex post pricing to ex ante controls; and 3) expand from a single pricing methodology to multiple pricing methods. Some of these ideas were incorporated in a document issued after the meeting entitled "Opinions on Further Pushing Forward the Reform of Work Concerning the Prices of Military Products" (关于进一步推进军品价格工作改革的指导意见).[392]

At the beginning of 2014, the GAD announced that it would conduct and expand upon pilot projects on equipment pricing. These reforms include strengthening the pricing verification of purchased goods, improving cost controls, shifting from singular to plural pricing models, from 'after-purchase pricing' to 'whole process pricing,' and from 'individual cost pricing' to 'social average cost pricing.'[393] These represent modest steps in the pricing reform process, but the PLA will continue to face fierce opposition from the defense industry on this issue.

Corruption

A fifth impediment is corruption, which appears to have thrived with the defense industry's uncertain transition from centralized state planning to a more competitive and indirect management model.[394] PLA leaders have highlighted the RDA system as one of a number of high-risk areas in which corruption can flourish (along with the selection and promotion of officials, the enrollment of students in PLA-affiliated schools, funds management, and construction work).[395]

At the PLA's annual conference on military discipline inspection work in January 2014, CMC Vice-Chairman General Xu Qiliang, who heads the PLA's anti-corruption efforts, pointed out that armament research, production, and procurement was one of two areas that required "better oversight."[396] The other area that Xu highlighted was construction projects, which has been plagued by a number of high-profile corruption scandals in recent years. These include the case of GLD Deputy Director Lieutenant General Gu Junshan, who amassed a huge fortune from lucrative real estate kick-backs.[397]

The almost complete absence of public reporting on corruption in the defense industry and RDA system means that the extent of the problem is not known. Military authorities justify this lack of

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390 Cheung, "An Uncertain Transition," 53.
391 Zong Zhaodun and Zhao Bo, "Major Reform Considered in Work on the Prices of Our Army's Armaments," *Liberation Army Daily*, November 13, 2009.
392 Ibid.
393 "Armament Work: It Is the Right Time for Reform and Innovation," *Liberation Army Daily*, February 13, 2014.
394 Corruption is defined broadly in China as covering the improper behavior of state, party, or military officials, but the more common Western definition is the abuse of public office for personal gain in violation of rules.
395 "PLA Gets Tough on Duty Crimes," Xinhua, December 1, 2014.
396 "CMC Vice Chairman Stresses Effective Anti-Corruption," *Liberation Army Daily*, January 17, 2014.
397 "How a PLA General Built a Web of Corruption to Amass a Fortune," *Caixin Wang*, January 16, 2014.

transparency as necessary because many of the cases could involve classified plans. In the latest anti-corruption crackdown that began with Xi Jinping's ascent to power at the 18th Party Congress in November 2012, only a handful of defense industry executives were arrested on corruption charges.[398]

Chinese Threats and US Responses

China's pursuit of a range of counter-intervention capabilities, including ballistic and cruise missiles, advanced aircraft and air defenses, and cyber and space capabilities poses a significant challenge to the United States and its allies.[399] First, China's deployment of such capabilities is constraining US options to project power and thereby undermining its credibility among allies and friends. Second, China's military modernization, and US responses to it, are imposing considerable costs. Third, China's defense investments have resulted in Beijing seizing the momentum in its competition with the United States; the United States is forced to respond to China's moves rather than vice versa.[400]

To date, China has been able to exploit geographic, political, technological, and doctrinal asymmetries to its advantage. Indeed, in each case China has been able to impose an unfavorable balance on the United States:

- In terms of geography, China has been able to exploit the tyranny of distance. Whereas the United States has to project power over thousands of miles to protect its interests, China has been able to pursue an "offensive defense" strategy to pursue its aims.
- In terms of alliances, China has been able to exploit the fact that the United States relies upon forward-based assets stationed on allied territory. Its defense investments both raise the cost of hosting US forces for allies and also undermine their confidence in US security guarantees.
- In terms of technology, China has been able to exploit the growth and spread of precision strike systems through the development and deployment of what the Soviets termed a "reconnaissance-strike system"—a network of sensors, command and control systems, and weapons allowing them to strike accurately at a distance.
- In terms of doctrine, China has developed capabilities aimed at defeating the US style of power projection, which relies upon fixed forward-based assets and large power projection forces centered on carrier strike groups.

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[398] See, for example, "Wu Hao, Deputy General Manager of AVIC Heavy Machinery Under Investigation for Corruption," *Xinjing Bao*, June 4, 2014.

[399] M. Taylor Fravel and Christopher P. Twomey, "Projecting Strategy: The Myth of Chinese Counter-Intervention," *Washington Quarterly* 37, No. 4 (Winter 2015), 171–87. Although Fravel and Twomey are narrowly correct that Chinese military doctrine does not explicitly contain a "counter-intervention" campaign, elements of Chinese campaign theory are clearly aimed at countering the intervention of an outside power in a regional conflict. Similarly, a significant portion of the Chinese force posture appears to have been developed and procured for that purpose.

[400] See, for example, Thomas G. Mahnken, "Armaments Developments Since the Cold War" and Tai Ming Cheung, "Racing from Behind: China and the Dynamics of Arms Chases and Races in East Asia in the Twenty-First Century," in Thomas Mahnken, Joseph Maiolo, and David Stevenson, eds., *Arms Races in International Politics: From the Nineteenth to the Twenty-First Century* (Oxford: Oxford University Press, 2016).

US policymakers have recognized for nearly a decade and a half that China's military modernization poses a growing challenge to US freedom of action in the Western Pacific. However, the Department of Defense has been slow to respond, mainly due to a focus on countering al-Qaeda and waging wars in Iraq and Afghanistan.[401]

Concern over China's military modernization, and the threat it poses to the United States and its interests, is long standing. For example, the 2001 Quadrennial Defense Review, which was drafted prior to the September 11, 2001 terrorist attacks, argued that the Defense Department's modernization efforts should focus on overcoming six emerging strategic and operational challenges:

1. protecting critical bases of operations, including the US homeland, forces abroad, allies, and friends, and defeating weapons of mass destruction and their means of delivery;
2. assuring information systems in the face of attack and conducting effective information operations;
3. projecting and sustaining US forces in distant anti-access or area-denial environments and defeating anti-access and area-denial threats;
4. denying enemies sanctuary by providing persistent surveillance, tracking, and rapid engagement with high-volume precision strike against critical mobile and fixed targets;
5. enhancing the capability and survivability of space systems and supporting infrastructure; and
6. leveraging information technology and innovative concepts to develop an interoperable, joint C4ISR architecture and capability that includes a joint operational picture that can be tailored to user needs.[402]

The first five of these challenges can be traced, at least in part, to Chinese military modernization efforts.

Not long after the 2001 QDR was completed, and before it was released, US defense strategy shifted markedly. The Defense Department's focus on Asia and the challenges associated with China's rise shifted to the Middle East and the threat posed by al-Qaeda and its affiliates. In October 2001, the United States launched Operation Enduring Freedom against al-Qaeda and its Taliban hosts in Afghanistan. In March 2003, the United States and its allies launched Operation Iraqi Freedom to overthrow the government of Saddam Hussein in Iraq.

Despite a growing commitment to the Middle East, the Defense Department recognized the growing challenge posed by China's acquisition of new military capabilities. The 2006 QDR argued that the pace and scope of Chinese military modernization was jeopardizing regional military balances and called for efforts to improve allied military capabilities, diversify the US basing structure in the Pacific, and pursue "investments that capitalize on enduring US advantages in key strategic and operational areas, such as persistent surveillance and long-range strike, stealth, operational manoeuver and sustainment of air, sea, and ground forces at strategic distances, air dominance, and undersea warfare."[403]

[401] Aaron L. Friedberg, *Beyond Air–Sea Battle: The Debate over US Military Strategy in Asia* (Abingdon: Routledge for IISS, 2014).
[402] US Department of Defense, "Quadrennial Defense Review Report," September 30, 2001, 30.
[403] US Department of Defense, "Quadrennial Defense Review Report," February 6, 2006, 29–30.

Concern over Chinese military modernization continued to grow under the Obama administration. The 2010 QDR emphasized the need to counter anti-access capabilities. As the report acknowledged:

> Anti-access strategies seek to deny outside countries the ability to project power into a region, thereby allowing aggression or other destabilizing actions to be conducted by the anti-access power. Without dominant US capabilities to project power, the integrity of US alliances and security partnerships could be called into question, reducing US security and influence and increasing the possibility of conflict.[404]

The report also called for the Navy and Air Force to develop a "joint air-sea battle concept for defeating adversaries across the range of military operations, including adversaries equipped with sophisticated anti-access and area denial capabilities."[405]

Air-Sea Battle

The advent of "Air-Sea Battle" thus represented the first large-scale, organized response to China's development of anti-access/area-denial capabilities. In August 2011, the Navy and Air Force established the Air-Sea Battle Office to manage the development and implementation of the Air-Sea Battle Concept.[406] The focus of the effort was to "preserve the [United States'] ability to defeat aggression and maintain escalation advantage despite the challenge posed by advanced weapon systems." Its "central idea" was to "develop networked, integrated forces capable of attack-in-depth to disrupt, destroy, and defeat adversary forces."[407] The initiative sought to increase cooperation and collaboration between the Navy and Air Force and to develop capabilities and concepts to counter anti-access/area denial capabilities and preserve the ability of US forces to project power in time of war.

Although few details of Air-Sea Battle were publicly released, the Congressional Research Service reported that "the Air-Sea Battle concept has prompted Navy officials to make significant shifts in the service's FY2014–2018 budget plan."[408] Moreover, in May 2012 Chief of Naval Operations Admiral Jonathan Greenert stated that the Air-Sea Battle Office had "more than 200 initiatives" in progress. He also commented that the 2011 and 2012 Presidential budgets included related investments in "anti-submarine warfare, electronic warfare, air and missile defense, and information sharing" and that the 2013 budget "sustains these investments and really provides more resilient C4ISR investments" in support of Air-Sea Battle.[409]

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[404] US Department of Defense, "Quadrennial Defense Review Report," February 2010, 31.
[405] Ibid., 31–32.
[406] On Air-Sea Battle, see General Norton A. Schwartz and Admiral Jonathan W. Greenert, "Air-Sea Battle: Promoting Stability in an Era of Uncertainty," *American Interest* (March-April 2012); Air-Sea Battle Office, "Service Collaboration to Address Anti-Access and Area Denial Challenges," May 2013, http://navylive.dodlive.mil/files/2013/06/ASB-26-June-2013.pdf.
[407] Air-Sea Battle Office, "Service Collaboration to Address Anti-Access and Area Denial Challenges."
[408] Ronald O'Rourke, "China Naval Modernization: Implications for US Navy Capabilities: Background and Issues for Congress," Congressional Research Service, July 28, 2015, 55.
[409] "Air-Sea Battle Doctrine: A Discussion with the Chief of Staff of the Air Force and Chief of Naval Operations," accessed September 11, 2015, http://www.brookings.edu/events/2012/05/16-air-sea-doctrine.

Adding to the Navy and Air Force work on Air-Sea Battle, in January 2012, the Joint Staff published the Joint Operational Access Concept, which details the use of joint forces to project power in an array of different operational contexts, including power projection that is contested by an adversary.[410]

Evaluating Air-Sea Battle is doubly difficult. Many of the early discussions of Air-Sea Battle originated with the think tank Center for Strategic and Budgetary Assessments, and predated the official effort.[411] The bulk of the official effort was classified, with few details publicly available. Nonetheless, scholars criticized Air-Sea Battle on several grounds.[412] First, some have portrayed Air-Sea Battle as a cynical attempt by the Navy and Air Force to magnify threats in order to lay claim to a larger share of a shrinking defense budgets.[413] Second, some have argued that it would spur an arms race with China. Third, some critics hold that Air-Sea Battle may make war with China more likely, "is highly escalatory and may lead to nuclear war."[414]

In arguing against Air-Sea Battle, some scholars have put forward alternative approaches to dealing with China's development of anti-access/area denial capabilities, including the use of 'offshore control' or a distant blockade of an adversary equipped with advanced precision strike systems.[415]

The secrecy under which Air-Sea Battle operated, combined with the difficulty that senior leaders had in explaining it, opened the effort to criticism. Moreover, in an era where jointness is seen as an unalloyed good, a Navy-Air Force initiative drew objections from the Army and Marine Corps. As a result, it was hardly surprising when in January 2015 the Department of Defense dropped the term "Air-Sea Battle" in favor of the inelegant and more bureaucratically acceptable "Joint Concept for Access and Maneuver in the Global Commons" and mandated participation of all four services in the effort.[416]

The Third Offset Strategy and the Defense Innovation Initiative

In light of China's continuing military modernization and dissatisfaction with Air-Sea Battle, senior defense officials have begun to formulate and implement more comprehensive responses.[417] Beginning in mid-2014, Deputy Secretary of Defense Bob Work began to discuss the need for the United States to undertake a "Third Offset Strategy" to counter the growing strength of potential

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[410] Joint Staff, *Joint Operational Access Concept,* Version 1.0, January 17, 2012.

[411] Jan van Tol, Mark Gunzinger, Andrew Krepinevich, and Jim Thomas, *AirSea Battle: A Point-of-Departure Operational Concept* (Washington, D.C.: Center for Strategic and Budgetary Assessments, 2010).

[412] See, for example, Amitai Etzioni, "Air-Sea Battle: A Dangerous Way to Deal with China," *Diplomat*, September 3, 2013, http://thediplomat.com/2013/09/air-sea-battle-a-dangerous-way-to-deal-with-china/; T. X. Hammes, "Sorry, AirSea Battle Is No Strategy," *National Interest*, August 7, 2013, http://nationalinterest.org/commentary/sorry-air-sea-battle-no-strategy-8846; and Elbridge Colby, "Don't Sweat AirSea Battle," *National Interest*, July 31, 2013, http://nationalinterest.org/commentary/dont-sweat-airsea-battle-8804.

[413] Jim Lacey, "Air-Sea Battle," *National Review,* December 14, 2011.

[414] Etzioni, "Air-Sea Battle: A Dangerous Way to Deal with China."

[415] T. X. Hammes, "Offshore Control: A Proposed Strategy for an Unlikely Conflict," National Defense University Strategic Forum 278, June 2012. See also Sean Mirski, "Stranglehold: The Context, Conduct, and Consequences of an American Naval Blockade of China," *Journal of Strategic Studies* 36, No. 3 (June 2013): 385–421.

[416] Sam LaGrone, "Pentagon Drops Air Sea Battle Name, Concept Lives On," *US Naval Institute News,* January 20, 2015, http://news.usni.org/2015/01/20/pentagon-drops-air-sea-battle-name-concept-lives.

[417] In the words of Deputy Secretary of Defense Bob Work, "Air Sea Battle, in my view, kind of went wrong." Quoted in Bill Gertz, "Gearing Up for Robot War," *Washington Times*, April 9, 2015, A12.

adversaries and retain US military advantage. Work has been the most outspoken champion of the approach, and his public speeches provide the best source of information on it.

In Work's view, the first instance of an offset strategy in recent US history had involved the Eisenhower administration's New Look strategy, which sought to use nuclear weapons to balance the Soviet Union's advantage in conventional forces in the early 1950s, while the second instance had coincided with the development of precision-guided munitions, sensors, stealth, and networking in the 1970s in response to the Warsaw Pact threat to Western Europe.[418]

According to Work, a new offset strategy is now needed because of the growth and spread of precision weaponry. Once an area of US dominance, the ability to launch precision strikes, including sensors, command and control capabilities, and weaponry, has spread to states such as China. As a result, the United States must adapt its approaches to combat. As Work put it in a 2015 speech,

> [to] maintain our warfighting edge, we're trying to address this erosion—our perceived erosion of technological superiority with the Defense Innovation Initiative and the third offset strategy. Now, as Secretary Hagel said, this new initiative is an ambitious department-wide effort to identify and invest in innovative ways to sustain and advance America's military dominance for the twenty-first century.[419]

One difference that Work noted between previous offset strategies and the current era was that US advantages were likely to be less enduring than in the past. As he put it, "we have potential competitors who are very, very good in this business and can duplicate—not only steal our [intellectual property]—but can duplicate things very fast. ... The last offset strategy lasted us for four decades. It is unlikely that the next one will last that long."[420]

In November 2014, Secretary of Defense Chuck Hagel institutionalized efforts to carry out the "Third Offset Strategy" by signing a memorandum that created the Defense Innovation Initiative (DII). According to the memo, the purpose of the DII is "to pursue innovative ways to sustain and advance [American] military superiority for the twenty-first century and improve business operations throughout the [Department of Defense]." Hagel noted that the United States was entering an era in which American dominance in key warfighting domains is eroding, and thus it needed to find new and creative ways to sustain and, in some areas expand, its advantages, even in the face of limited resources. Noting that "potential adversaries have been modernizing their militaries, developing and proliferating disruptive capabilities across the spectrum of conflict," he argued that "we must take the initiative to ensure that we do not lose the military-technological superiority that we have long taken for granted."[421] Specifically, he called for:

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[418] The use of the term 'third offset' is somewhat anachronistic, as it was in the 1970s during the now-second offset that the term 'offset strategy' was first coined.

[419] US Department of Defense, "The Third US Offset Strategy and its Implications for Partners and Allies," speech by Deputy Secretary of Defense Bob Work, Willard Hotel, Washington, DC, January 28, 2015, http://www.defense.gov/News/Speeches/Speech-View/Article/606641/the-third-us-offset-strategy-and-its-implications-for-partners-and-allies.

[420] Sydney Freedberg, Jr., "Adversaries Will Copy 'Offset Strategy' Quickly: Bob Work," *Breaking Defense*, November 19, 2014.

[421] Chuck Hagel, Memorandum, "The Defense Innovation Initiative," November 15, 2014, 1.

- Rethinking how the Defense Department develops managers and leaders;
- Establishing a "long-range research and development planning program [to] identify, develop, and field breakthrough technologies and systems that sustain and advance the capability of US military power";
- Reinvigorating war gaming to develop and test alternative ways of achieving strategic objectives and help the Defense Department think more clearly about the future security environment;
- Developing new operational concepts to explore how to achieve greater strategic effect and deal with emerging threats in innovative ways.[422]

In announcing the DII, Hagel noted:

> For decades, America's leadership in the world has been anchored not only by our global military presence, but also by our military's unrivaled technological and operational superiority—an edge that has enabled our nation to project power rapidly across the globe. But America's military superiority has never been guaranteed, and it confronts significant challenges on the horizon. Technologies and weapons that were once the exclusive province of advanced nations have become available to a broad swath of militaries and non-state actors. Countries like Russia and China have been heavily investing in military modernization plans tailored to blunt our military's technological and operational edge.

As he concluded, "Going forward, I expect the Defense Innovation Initiative to significantly shape DOD priorities. As the initiative develops over time, so will its impact on DOD's budget, plans, and programs."[423]

Although it is too early to render a final judgment as to whether the initiative will survive the 2016 elections and the transition to a new administration, there is reason to believe that it will. The perception that China's military modernization is jeopardizing US interests in the Western Pacific is both widespread and bipartisan. Moreover, the inadequacy of existing defense plans to respond to that threat is increasingly apparent. As a result, it is likely that future administrations will continue, and perhaps strengthen, the initiative.

The shape of the "Third Offset Strategy" is still coming into focus as well. According to Deputy Secretary Work, to realize the strategy, the Defense Department is increasing its investment in new space capabilities; advanced sensors, communications and munitions for power projection in contested environments; missile defense; and cyber capabilities. The department is also investing in promising new technologies, such as unmanned undersea vehicles; advanced sea mines; high-speed strike weapons; advanced aeronautics; autonomous systems; electromagnetic rail guns; and high-energy lasers.[424] Some of these technologies show promise. If, for example, the United States were to field militarily effective rail guns or lasers, the task of missile defense would become much

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[422] Chuck Hagel, Memorandum, 1–2.
[423] Chuck Hagel, "A New Era for the Defense Department," November 18, 2014, DefenseOne website, http://www.defenseone.com/ideas/2014/11/new-era-defense-department/99392/print/.
[424] US Department of Defense, "The Third US Offset Strategy."

easier than it has been heretofore. However, many these systems have yet to prove themselves in an operational setting and are unlikely to be deployed before the 2020s at the earliest.

As Work put it in a speech at the Army War College, "The real essence of the third offset strategy is to find multiple different attacks against opponents across all domains so they can't adapt, or they adjust to just one, and they died before they can adapt again." He likened the process to chess: "I believe that what the third offset strategy will revolve around will be three-play combat in each dimension … three-play combat will be much different in each dimension [air, sea, land], and it will be up to the people who live and fight in that dimension to figure out the rules."[425]

The "Third Offset Strategy" remains a work in progress. To be effective over the long run, US responses to Chinese strategy should exploit US relative strengths and Chinese weaknesses. Moreover, such a strategy should have three features. First, it should yield an expanded set of US options while constraining those of the Chinese. Second, it should give us momentum in the competition with China, forcing Beijing to respond to our moves. Third, it should impose considerable costs upon China as it responds.

Shaping a Long-Term US Response

A US response should seek to gain an asymmetric advantage in the areas of geography, alliances, technology, and doctrine. In terms of geography, such a strategy should seek to use Asia's strategic geography—in particular, the barrier formed by Japan, Taiwan, and the Philippines—to constrain China's access to the Western Pacific in time of crisis or war. This could be accomplished by fielding sensor and engagement networks both unilaterally and in cooperation with allies along China's maritime flanks. Associated technologies would include undersea sensors, various airborne sensor systems, and land- and sea-based strike systems. Such an approach would capitalize upon the combination of geography, which constrains China's access to the Pacific Ocean, and existing US and allied sensor plans, which promise to give the United States and its allies greater situational awareness of activities in the air and on or under the sea. Japan, for example, is fielding a constellation of reconnaissance satellites, expanding its air- and surface-search radar network, and modernizing its force of land-based anti-ship cruise missiles. The United States, for its part, is considering exports of unmanned aerial vehicles (UAVs) such as the RQ-5 Global Hawk to a number of allies in the region, such as Australia and South Korea. Similarly, a number of US allies, including Japan and Australia, possess capable fleets of anti-submarine warfare aircraft. The Japan Maritime Self-Defense Force possesses four squadrons of P-3C *Orion* aircraft, which it is replacing with the Kawasaki P-1; the Royal Australian Air Force is replacing its two squadrons of AP-3Cs with the Boeing P-8 *Poseidon*.[426]

The United States should also deepen its interoperability with allies to bolster their capabilities and strengthen their will. The United States already shares information with its allies, and the case for increasing that cooperation is strong.[427] Washington should consider building on this by establishing an open-architecture ISR network in the Western Pacific to complement current bilateral

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[425] US Department of Defense, "Army War College Strategy Conference," speech delivered by Deputy Secretary of Defense Bob Work, US Army War College, Carlisle, Pennsylvania, April 8, 2015, http://www.defense.gov/News/Speeches/Speech-View/Article/606661.

[426] *The Military Balance*, 231, 259.

[427] See, for example, Patrick M. Cronin and Paul S. Giarra, *Robotic Skies: Intelligence, Surveillance, Reconnaissance, and the Strategic Defense of Japan* (Washington, DC: Center for a New American Security, 2010).

information-sharing agreements. Support for broad information sharing in the Western Pacific is likely to grow in the face of Chinese encroachment. Given the increasing quality and declining cost of both commercial imagery and the sensors that produce it, such an approach will be feasible for a growing number of states.

The United States should also deepen cooperation in the areas of theater strike with key allies. The requirement for Australia's next-generation attack submarine includes a strike capability, something the United States should support. Similarly, the United States should seek to support Australian efforts to expand their air and naval surface strike capabilities.

Undersea warfare, in terms of both submarines and unmanned underwater vehicles, is another area for cooperation. The United States should offer to sell or lease *Virginia*-class nuclear-powered submarines (SSNs) to Australia as the replacement for the *Collins*-class submarine and should deepen cooperation with Japan in undersea warfare. It should consider developing innovative approaches to expand the strike capability of US and allied submarines, to include the development of the Towed Payload Module for the *Virginia*-class SSN and potentially for export. It should also work with allies and friends against coercion to make their networks more resilient and to harden key ports and airfields against attack. The goal would be to have a wide variety of facilities that US forces could utilize in time of war. Finally, allies and friends should be provided with counter-invasion capabilities, to include land-based anti-ship cruise missiles, naval mines, and precision-guided rockets and artillery systems.

In terms of technology, the United States should both develop and deploy countermeasures to hostile precision strike as well as move into the next phase of the precision strike competition. Counters to precision strike include hardening and dispersal of key facilities, countermeasures to precision navigation and timing, and the development of directed energy weapons to destroy precision weapons. The United States should also exploit its dominance in the undersea domain by greatly increasing its subsurface strike capability. At the same time, the United States should develop autonomous systems to mitigate the vulnerabilities inherent in reconnaissance-strike systems (such as the links between sensor, decider, and shooter). Although the United States is pursuing these technologies, such efforts are constrained both by limited budgets and technological feasibility. Finally, although the United States is currently constrained by the Intermediate-Range Nuclear Forces Treaty from developing and deploying land-based ballistic and cruise missiles with a range of between 500 and 5,500 kilometers, no such constraint exists on sea-based systems.

The United States should also safeguard its technological edge by redoubling efforts to deny China access to strategic technologies. China has proven adept at pursuing a fast-follower strategy of acquisition, buying or stealing technology and the underlying intellectual property from both the United States and Russia. Efforts to deny China easy access to US military technology and intellectual property will, at the least, drive up the cost in terms of time and effort that China is forced to expend to acquire it. In other cases, such efforts may force China to seek less capable substitutes for US technology.

Technology transfer restrictions also need to be updated, both to reflect the current international technology market as well as to maximize their effectiveness. It is in the national interest for the US government and private industry to work cooperatively to develop best practices and share threat information. To be effective, however, such measures should prioritize the technologies that are likely to provide the greatest battlefield edge in the future. These include space and cyber capabilities, unmanned systems, high-speed propulsion, advanced aeronautics, autonomous systems, electromagnetic rail guns, and directed-energy systems.

In terms of doctrine, the United States should exploit the weaknesses inherent in a centralized approach to warfare, including the need to gather and process large volumes of information. Chinese military doctrine displays a strong belief that strategy is a science rather than an art and maintains great confidence in its ability to predict the outcome of conflicts.[428] In order to bolster deterrence, the United States and its allies should work to reduce the confidence of the Chinese leadership in its ability to control the course and outcome of a future conflict.

Such an offset strategy, if implemented consistently over time, holds the promise of influencing Chinese actions at the tactical, operational, and strategic level. Tactically, it would erode the effectiveness of Chinese counter-intervention systems. Operationally, it would deny the PLA leadership the type of war it has been planning for decades, forcing it to either double-down on its investment in anti-access capabilities or seek a new approach. But its greatest promise is likely to be strategic: such an approach holds the potential to alter the decision-making calculus of the leadership of the CCP. A strategy of this type could markedly increase the cost of pursuing a strategy of maritime expansion and potentially rechannel Chinese attention away from its maritime flanks and toward the Asian continent. It would increase the cost of challenging international norms and hopefully give the Chinese leadership greater incentives to accept significant elements of the existing international order.

Reductions in the defense budget have hurt the ability of the United States to respond to threats to US interests and forces. Both Budget Control Act limits and uncertainty over the level of future budgets have harmed the ability of the Defense Department to acquire the capabilities that the United States needs to safeguard US interests in an increasingly contested environment. In particular, the United States faces a growing need to develop and acquire innovative new capabilities at the very time that resources available to field new capabilities is increasingly constrained. Moreover, in a period in which existing plans face budgetary pressure, there is little appetite to field additional capabilities, however promising. In an environment where acquisition dollars are increasingly rare, the defense industry and university-affiliated research centers will need to take a greater role in developing innovative capabilities through advanced research, development, and prototyping.

The Emergence of Direct US–China Defense Technological Competition

While the Third Offset Strategy and the DII are focused at rectifying the overall global erosion in US defense technological pre-eminence, the top challenge over the next 25–30 years comes from the ‘great powers’ of Russia and China. Although the Pentagon is deeply concerned with Russian aggression in the short to medium term, China “embodies a more enduring strategic challenge,” according to US Deputy Defense Secretary Work.[429] The Third Offset Strategy and the DII have a number of characteristics, in which China looms large as the ‘pacing threat’:

[428] Thomas G. Mahnken, *Secrecy and Stratagem: Understanding Chinese Strategic Culture* (Sydney: Lowy Institute, 2011).
[429] “Work Outlines Key Steps in Third Offset Tech Development,” *Defense News,* December 14, 2015.

- **Conventional deterrence against great powers:** The central tenet of the US strategy is to develop a dominant conventional deterrent against Russia and China that reduces the chances of major military conflict between them.
- **Asymmetric competition:** Avoid competing in quantitative arms races with potential adversaries and instead focus on developing technologically superior quality that would compensate for the numerical superiority enjoyed by these rivals.
- **Strategy based, technology-oriented:** While technology is important, operational strategies and organizational constructs are also key elements in gaining advantages against numerically stronger opponents.
- **Operational level of war:** The primary focus of the initiatives is in the operational planning and conduct of campaigns that consist of assigning missions, tasks, and resources to military organizations. The principal operational concerns that the Defense Department has are:[430]
    1. the growing vulnerability of its global system of military bases, especially those that are close to major potential adversaries in the Asia-Pacific and Europe;
    2. the increasing ability of opponents to detect, track, and engage US aircraft carriers and other major surface warships at extended ranges from their coasts;
    3. the build-up of modern integrated air defense systems that are making it increasingly difficult for US and allied airpower to enter into contested opposition airspace; and
    4. the militarization of space that no longer makes it a sanctuary from military conflict.

Senior DOD officials have acknowledged that the origins of the Third Offset Strategy came from the threat posed by China. Speaking at a defense forum in November 2015, Bob Work disclosed that the DOD first began to think about a new offset strategy in the early 2010s when Ashton Carter, who was Deputy Defense Secretary at the time, established the Strategic Capabilities Office "focused on the advanced capabilities that we were seeing in the Western Pacific." [431] The only country undertaking these developments was China.

While the Third Offset Strategy and the DII are still in their preliminary stages of development, they do signal that the United States has unambiguously taken its first consequential steps in engaging China directly in defense technological competition. From a US defense acquisition perspective, these strategies are being operationalized in the Long-Range Research and Development Planning Program (LRDPP), which is modeled on an effort started in the 1970s when the United States successfully offset Soviet military numerical superiority with disruptive technological capabilities such as stealth and precision strike.[432]

US Undersecretary of Defense for Acquisition, Technology, and Logistics Frank Kendall, who is in overall charge of the LRDPP, provided a succinct assessment of the military technological threat

[430] Robert Martinage, *Towards a New Offset Strategy* (Washington, DC: Center for Strategic and Budgetary Assessments, 2014), 23–32.
[431] Remarks by Bob Work on the Third Offset Strategy at the Reagan Defense Forum, November 7, 2015, http://www.defense.gov/News/Speeches/Speech-View/Article/628246/reagan-defense-forum-the-third-offset-strategy.
[432] "DoD Seeks Future Technology Via Development Plan," *DOD News*, December 3, 2014, http://www.defense.gov/News-Article-View/Article/603745.

posed by China at a Congressional hearing in January 2015, articulating the geostrategic context for the renewed innovation drive by the DOD:

> China has developed and fielded advanced weapons designed to defeat US power projection forces. Many more are in development. These systems include a range of capabilities, but foremost among them are accurate and sophisticated cruise and ballistic missiles designed to attack high-value assets; particularly the aircraft carriers and airfields that we depend upon for power projection. These missiles, fielded in large numbers and coupled with advanced electronic warfare systems, modern air-to-air missiles, extensive counter-space capabilities, improved undersea warfare capabilities, fifth-generation fighters, and offensive cyber weapons pose a serious and growing threat.[433]

A number of new and emerging high technologies, especially in the areas of artificial intelligence and autonomy, have been revealed as the initial focus of the Third Offset Strategy and DII in order, as Work argued, "to deter" against potential adversaries:[434]

- **Autonomous 'deep learning' machines and systems:** The Pentagon wants to develop these capabilities to improve its early warning and prediction of events.
- **Human-machine collaboration:** This refers to how machines can interface with humans to assist with decision-making. One example is the development of highly advanced helmets for fighter pilots, such as with the F-35 Joint Strike Fighter, which fuses data from multiple systems that then can be more easily digested for the pilot.
- **Assisted-human operations:** Research is being targeted at how machines can help humans operate more effectively. DARPA, for example, has been developing an experimental 'Iron Man' exoskeleton suit. This research is different from "enhanced human operations" that focus on modifying the human body and brain, and which Work claims that "our adversaries are pursuing, and it scares the crap out of us, frankly."[435]
- **Human-machine combat teaming:** This refers to leveraging the unique advantages of people and machines, including robotics and artificial intelligence, into hybrid teams with the goal of delivering decisive advantages on the battlefield. This is already being applied, for example, with the teaming up of human operators and unmanned systems such as the US Army's Apache helicopter and Gray Eagle unmanned aerial vehicle or the US Navy's P-8 Reconnaissance aircraft and the MQ-4C Triton Unmanned Carrier-Launched Airborne Surveillance and Strike drone.
- **Network-enabled, semi-autonomous weapons hardened for electronic and cyber warfare environments:** Many of the US military's weapons and systems are semi-autonomous and connected to vulnerable networks that will require modification and hardening to prevent being disabled by increasingly sophisticated electronic and cyber warfare attacks, much like protection against an electro-magnetic pulse attack during the Cold War. Work is taking place, for example, to make the Small Diameter Bomb operate autonomously without reliance on GPS information to direct it to its target.

[433] Testimony of Frank Kendall before the US House Armed Services Committee, January 28, 2015.
[434] Remarks by Work at Reagan Defense Forum; Bob Work, speech at the CNAS Defense Forum, Washington, D.C., December 14, 2015, http://www.defense.gov/News/Speeches/Speech-View/Article/634214/cnas-defense-forum.
[435] Remarks by Work at Reagan Defense Forum.

Chinese Views of Direct US–China Defense Technological Competition

Perceptions among China's defense and national security policymakers and planners that the United States is becoming a direct military competitor and potential adversary have gained ground in response to the proliferating array of security frictions and deepening strategic distrust between the two countries, although the official Chinese views are usually more circumspect. Wang Jisi, an influential and well-placed academic foreign policy adviser to the Chinese leadership, pointed out in a study of US–China strategic trust in 2012 that "some high-ranking Chinese officials have openly stated that the United States is China's greatest national security threat. This perception is especially widely shared in China's defense and security establishments and in the Communist Party's ideological organizations."[436]

These views about the increasingly contested nature of US–China security relations and interests have yet to be reflected in any authoritative Chinese strategic and military doctrines and policies that have been made public. These have tended to be more guarded in their assessments of the United States because China's overarching strategic priority continues to be focused on economic development, which can only be effectively carried out in a non-antagonistic security environment.

In discussing the regional security situation surrounding China, the 2015 Chinese defense white paper pointed out that "as the world economic and strategic center of gravity is shifting ever more rapidly to the Asia-Pacific region, the United States carries on its 'rebalancing' strategy and enhances its military presence and its military alliances in this region."[437] The white paper is a little more circumspect in mentioning the United States in its assessment of intensifying global defense technological competition and its implications for China's national security:

> The world revolution in military affairs is proceeding to a new stage. Long range, precise, smart, stealthy and unmanned weapons and equipment are becoming increasingly sophisticated. Outer space and cyber space have become new commanding heights in strategic competition among all parties. The form of war is accelerating its evolution to informationization. World major powers are actively adjusting their national security strategies and defense policies, and speeding up their military transformation and force restructuring. The aforementioned revolutionary changes in military technologies and the form of war have not only had a significant impact on the international political and military landscapes, but also posed new and severe challenges to China's military security.[438]

Although official Chinese documents and policies are silent as to whether China's military developments are in response to perceived threats and actions from the United States, there is discussion of these action–reaction dynamics among security analysts, scholars, and writers that work in think tanks, universities, and media outlets affiliated with the military, state, and Communist Party.[439] In an assessment of the air-sea battle concept that is at the heart of the US strategic pivot to the Asia-Pacific region, one Chinese military academic argued that

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[436] Kenneth Lieberthal and Wang Jisi, *Addressing US–China Strategic Distrust* (Washington, DC: Brookings Institution, 2012), 13.

[437] State Council Information Office, "China's Military Strategy."

[438] Ibid.

[439] Michael Swaine, "Chinese Leadership and Elite Responses to the U.S. Pacific Pivot," *China Leadership Monitor* 38 (Summer 2012).

> the introduction of the "air-sea battle" concept may possibly further worsen mutual military trust. Once the United States decides to readjust its military preparations in the Asia-Pacific region, it will inevitably cause the allies of the United States in the region to readjust their military deployments in a corresponding manner, and in order to uphold national security, China will also respond to this in a corresponding manner. This kind of chain reaction in the military security realm may lead to an intense arms race.[440]

While there is little open discussion by Chinese military or civilian officials about the technological threat posed by the United States, they have been responding vigorously at the RDA level since the end of the 1990s, most notably with the 995 Plan, which can be looked at as the counterpart to the Third Offset Strategy and the DII.

Moreover, senior Chinese leaders have been hinting in the past several years that the country's long-term weapons development strategy may also be due for major revision or replaced by a new version that places even greater emphasis on accelerated technological development, more advanced innovation, and in new and emerging domains. At a keynote speech to the All-Army Armament Conference in December 2014, Xi Jinping said that "facing the new situation and new tasks, the strategic guidance for armament building must adapt to the times." He noted that the "present time and for a period to come mark a window of strategic opportunity for our military's armament building and also a crucial stage for making leapfrog development."[441]

Another indicator that planning of a new development strategy is taking place was the announcement by SASTIND in June 2015 that it was establishing a defense S&T development strategy committee to conduct research and provide policy input that would help the country's leadership in its decision-making on long-term defense R&D.[442] This was followed by the establishment of a Central Military Commission Science and Technology Commission (CSTC) as part of far-reaching military structural reforms. The STC was originally an S&T advisory body under the GAD, but its elevation to the CMC suggests that it may serve as a counterpart to the SASTIND defense S&T development strategy committee. Among the CSTC's publicized responsibilities are: 1) strengthening the strategic management of defense S&T; 2) promoting indigenous innovation; and 3) advancing the integration of military and civilian S&T.[443]

In conclusion, the defense S&T development efforts in which the United States and China are now engaged appear to be increasingly directed at each other. While it may not yet be intensive and hugely expensive competition that occurred at the height of the Cold War, there are beginning to be many similarities to this earlier period.

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[440] Hu Xin, "'Air-Sea Battle' Sword Pointed at East Asia," *Contemporary Military Affairs*, October 5, 2011.
[441] Tang Xiuying and Zong Zhaodun, "Xi Jinping Attends PLA Armament Work Conference."
[442] Yu Xiaojie and Guo Likun, "Development Strategy Committee for Defense Science, Technology, and Industry Established, CAS and CAE Presidents Lend Their Prestige," Xinhua, June 4, 2015.
[443] "Former GAD S&T Committee Director Liu Guozhi Appointed Director of New CMC S&T Committee."

B. IMPLICATIONS FOR US ECONOMIC COMPETITIVENESS

In this section, the report addresses the near to long-term implications for US economic competitiveness from China's assortment of state-led development plans. Attention is first paid to strategic principles and policy instruments that shape the nature and guide the implementation of these plans. This is followed by an examination of eleven case studies to explore more deeply the current and future implications of China's state plans at the industry level.

Two overarching principles and policy instruments in Chinese innovation policy are first discussed: techno-national opportunism and indigenous innovation. These principles drive Chinese innovation policy, priorities, and actions in China's government circles and high-tech industry. Put succinctly, techno-nationalism is the belief that a state-controlled and closed-door approach to technological and industrial development is the best way to safeguard national security, economic competiveness, and international status. Indigenous innovation is defined as a way to promote original innovation, re-assembling existing technologies in different ways to produce new breakthroughs, and the absorption and upgrading of imported technologies. Both principles inherently lead to an inclination to protect domestic industries by designing policies and incentives that favor local actors and discriminate against foreign enterprises.

Six policies are examined that operationalize these techno-nationalist and indigenous innovation principles:

1. Sectoral protectionism
2. The cultivation of local and national champions
3. Trading market access for technology transfers
4. The use of state catalogues to regulate investment and technology imports
5. The promotion of Chinese technology standards domestically and internationally
6. An increasingly vigorous "going out" strategy to open up foreign markets for Chinese product

Some of these policies, such as the "going out" strategy and state catalogues, are well-publicized and feature prominently in the Chinese state plans and development strategies. Other more controversial policies, such as protectionism and nurturing of champions, are more implicit and applied indirectly. All of these policies represent major challenges for US economic competitiveness.

To better understand the economic implications from these policies and other factors associated with China's development efforts, eleven industry sectors have been selected for in-depth examination. The case studies are laid out in accordance with an analytical framework detailed later in this section. Of prime importance are market characteristics, relative technology levels of US and Chinese firms, and policy measures. These factors are applied to determine the levels of direct competition to US firms and the demand for US parts, technology, and IP and to gauge the current, short-, medium-, and long-term implications for US economic competitiveness. The case studies are grouped into four areas:

1. **Information and communications technology (ICT):** 5G technology, cloud computing, global navigation satellite systems, and integrated circuits
2. **Manufacturing:** Additive manufacturing, advanced robotics, and nanomaterials

3. **Transportation:** Electric vehicles and high speed rail
4. **Medical and healthcare:** Biopharmaceuticals and medical devices

One of the main conclusions from these case studies is that over the long term, US high-tech industries will move from largely positive or limited impacts on their competitiveness from Chinese state plans to largely negative or mixed impacts. Due to Chinese techno-nationalist and indigenous innovation policies, many US firms currently face strong challenges as they attempt to enter the Chinese market. Yet by and large, the full intention of China's policies has not been fulfilled. In sectors where China has not been able to cultivate national champions to dominate local markets and compete globally, there is still great demand within China for US products and suppliers. With the continuing implementation of these Chinese policies over the longer term, US firms may find themselves increasingly marginalized or pushed out of Chinese markets, and this will undoubtedly have negative implications for US jobs and production.

A further examination of the effects of China's state plans on the US labor market and production suggests that the impact will be primarily felt within the Chinese market rather than in the United States. US companies that have sizeable production capabilities and workforces in China are likely to be threatened by policies that provide subsidies and protection to domestic players. In addition, compared to traditional sectors like steel and auto parts, production activities and workforces in high-tech and emerging sectors are less likely to be impacted.

Core Principles and Policy Instruments in Chinese State Development Plans

Chinese state plans for S&T, industrialization, and energy development have a number of overarching principles and policy instruments that have considerable implications for the long-term economic competitiveness of the United States and other countries around the world. Two of these strategic principles are especially significant and will be discussed in detail: techno-national opportunism and indigenous innovation. In the pursuit of these principles, the Chinese authorities have devised a set of policy instruments that are being vigorously implemented. Six of these policies will be examined: 1) sectoral protectionism; 2) the cultivation of local and national champions; 3) pushing hard for technology transfers; 4) the use of state catalogues to regulate investment and technology imports; 5) the promotion of Chinese technology standards domestically and internationally; and 6) an increasingly vigorous "going out" strategy to open up foreign markets for Chinese products as well as to secure energy and other critical supplies for the country.

The implementation of these policy instruments will vary by industry, but they are most likely to be applied in sectors that are considered to be of strategic importance and value. What the Chinese authorities constitute as a 'strategic industry' (战略性产业) is far from clear. The label appears to be constantly evolving and influenced by changing political, economic, and/or national security considerations. There are core strategic industries that are defined by their direct relevance to national security, such as the defense industry, but other sectors that have been classified as strategic by the Chinese government include emerging industries covered by the SSEI and those deemed to be critical to the national infrastructure, which can be very broad and covers automobiles, finance, energy, utilities, and telecommunications.[444]

[444] Roselyn Hsueh, *China's Regulatory State: A New Strategy for Globalization* (Ithaca, NY: Cornell University Press, 2011).

The Chinese authorities also use the concept of ‘pillar industry’ (支柱性产业), which, according to one World Bank study, originated in the mid-1990s and was based on a number of economic criteria that included high income elasticity of demand, enjoyed economies of scale, had significant production linkages and potential for high productivity growth, and reflected China’s comparative advantage.[445] The initial industries that were designated pillar industries were machinery, electronics, petrochemicals, automobiles, and construction.

One concern with the Xi Jinping regime is that it has adopted a far more expansive view of what constitutes national security than previous administrations. This could lead to more industrial sectors being designated as strategic in nature. The 2015 National Security Law, for example, identifies 11 areas that are important to national security: political, territorial, military, economic, cultural, social, ecological, science and technology, information, nuclear, and natural resources.[446] The law also requires that technology that supports crucial sectors must be “secure and controllable.”[447]

Techno-Nationalist Opportunism

Techno-nationalism is a fundamental principle in the thinking of Chinese policymakers in science, technology, and industrial development. Techno-nationalists believe that a state-controlled and closed-door approach to technological and industrial development is the best way to safeguard national security, economic competiveness, and international status. Emphasis is placed on nurturing indigenous capabilities through adoption of highly regulated protectionist regimes that sharply restrict FDI but encourage the one-way importation of advanced technology and knowledge.

The MLP is a leading example of a plan that is avowedly techno-nationalistic in nature. The MLP argues that the only way that China can advance against international competition is to “improve its independent innovative capabilities and master a number of core technologies, own a number of proprietary intellectual property rights and groom internationally competitive enterprises in important fields.” To achieve this, one of the central concepts in the MLP is the notion of indigenous innovation. This term is viewed “by some as a regression to the self-defeating techno-nationalist notions of self-reliance from the Maoist era,” although the MLP seeks to define this concept not only from an ideological viewpoint but also from a functional perspective.[448]

The key elements of contemporary Chinese techno-nationalist doctrine that can be found in the MLP and other plans are:

- Technological development is strategic and has implications for the relative position of the state in the global military and economic balance.
- The state must invest in critical technological sectors because of the high risks and lengthy time cycles involved in high-technology R&D.
- The state should pursue import-substituting indigenization.
- The state must nurture an indigenous capacity to innovate.

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[445] Vikram Nehru, Aart Kraay, and Xiaoqing Yu, eds., *China 2020: Development Challenges in the New Century* (Washington DC: World Bank, 1997), 39.
[446] “China Approves Sweeping Security Law, Bolstering Communist Rule,” *New York Times*, July 1, 2015.
[447] “Jitters in Tech World Over New Chinese Security Law,” *New York Times*, July 2, 2015.
[448] Cao, Suttmeier, and Simon, “China’s 15-Year Science and Technology Plan,” 40.

- Technology diffusion, whether through spin-offs or spin-ons, should be a central long-term goal.

This techno-nationalist ideology coexists with a healthy dose of pragmatic opportunism that allows for flexibility and compromise in policy choices. In particular, this allows for the embrace of more inclusive techno-globalist approaches, especially if this helps to advance technological innovation more rapidly and effectively.

China embraced key elements of techno-globalist thinking in the early 1990s by opening up the national economy to FDI and rolling back state dominance of the S&T system by allowing the participation of private and other non-state firms.[449] This led to massive inflows of foreign investment into the medium and high-technology sectors by multinationals, and soaring imports of technology goods by foreign and Chinese firms throughout the 1990s. In addition, large numbers of entrepreneurial domestic and foreign joint venture new technology enterprises were established or spun off from the state sector and quickly emerged as major players in the domestic technology marketplace.

China's technology development strategy has evolved into a pragmatic and sometimes messy hybrid that incorporates both competing and complementary strands of techno-nationalist and techno-globalist thinking. With these two camps firmly entrenched and wielding extensive influence among policymakers and key state agencies, there are occasional adjustments in technology-related policies to accommodate their different interests.[450] A prime example of such an outcome occurred in 2009 when China issued indigenous innovation procurement guidelines requesting that government agencies should only buy technology products containing domestic intellectual property. The move drew strong condemnation from foreign companies and governments, which argued that the policy went against established international norms, and the Chinese government eventually retreated from this initiative.[451]

The procurement guidelines controversy reflects a broader effort by China to promote its own homegrown technical standards within the global technology system. The setting of international technical standards has traditionally been in the hands of multinational corporations, but China has raised its profile since the beginning of the twenty-first century, especially in areas such as telecommunications, digital audio and video, computer microprocessors, wireless local area network security, and Internet protocols. The MLP explicitly calls for China to "actively take part in the formulation of international standards and drive the transferring of domestic technological standards to international standards." Richard Suttmeier and Yao Xiangkui argue that China's technical standards strategy should be understood as a modified form of techno-nationalism, in which "technological development in support of national economic and security interests is pursued through

[449] Barry Naughton and Adam Segal, "Technology Development in the New Millennium: China in Search of a Workable Model," in C*risis and Innovation: Asian Technology After the Millennium,* eds. William Keller and Richard Samuels (New York: Cambridge University Press, 2002), 170−76.
[450] State entities that are most supportive of techno-nationalist approaches include the NDRC, MIIT, and PLA. Organizations that are more techno-globalist in orientation include MOFCOM and MOFA.
[451] Loretta Chao, "China's Curbs on Tech Purchases Draw Ire," *Wall Street Journal*, December 11, 2009; US-China Business Council, "China's Innovation and Government Procurement Policies," May 1, 2013, https://www.uschina.org/sites/default/files/innovation-status-report.pdf.

leveraging the opportunities presented by globalization for national advantage."[452] How China flexes its growing technological power in this area will offer a good indicator of where the balance between techno-nationalist and techno-globalist impulses lies in its evolving techno-hybrid framework.

Indigenous Innovation

Hand in glove with techno-nationalism is the concept of indigenous innovation, which is widely referred to in Chinese state plans. What indigenous innovation actually means, however, is far from clear. The term first appeared in the MLP and is defined as a way to promote original innovation, re-assembling existing technologies in different ways to produce new breakthroughs, and the absorption and upgrading of imported technologies. The MLP puts forward three distinct models:

1. **Original innovation (*yuanshi chuangxin,*** 原始创新): This refers to scientific discovery and technological invention carried out by Chinese research institutions that eventually are successfully developed and commercialized. The meaning of original innovation appears to have expanded in recent years to include an emphasis on breakthrough innovation.
2. **Integrated innovation (*jicheng chuangxin,* 集成创新):** This means the synthesis of related technologies and processes that facilitates the development of competitive products and industries. These technologies and processes can be both foreign and domestic.
3. **IDAR (introduction, digestion, assimilation, re-innovation):** This model is based on the identification, acquisition, and absorption of foreign technologies and processes through a multi-stage sequence of introduction (*yinjin,* 引进), digestion (*xiaohua,* 消化), and assimilation (*xishou,* 吸收) that leads to re-innovated (*zaichuangxin,* 再创新) output. This can be concisely referred to as the IDAR (Introduce, Digest, Assimilate, Re-innovate) strategy and can also be described as advanced imitation.[453]

Of these three approaches, IDAR is the most important and relevant to China's current S&T needs. A more detailed discussion of IDAR can be found in the section "Chinese Priorities for Technology Acquisitions from the US and Foreign Countries" (pages 117–23).

During Hu Jintao's presidency, indigenous innovation was the main policy focus and was reiterated in China's 12th FYP and in the SEI initiative. Xi Jinping's administration has come up with the new more market-friendly 'innovation-driven development' concept that embraces bottom-up innovation at the same time that it continues to emphasize top-down approaches. Although indigenous innovation as a phrase is now referred to less frequently by senior leaders and in policy documents, its core tenets continue to be the closely observed. In the 13th FYP outline, for example,

[452] Richard P. Suttmeier and Yao Xiangkui, *China's Post-WTO Technology Policy: Standards, Software, and the Changing Nature of Techno-Nationalism,* National Bureau of Asian Research Special Report No. 7 (May 2004), 3. See also Christopher S. Gibson, "Technology Standards: New Technical Barriers to Trade?" in *The Standards Edge: The Golden Means,* ed. Sherrie Bolin (Ann Arbor, MI: Bolin Group, 2007). On China's involvement in global Internet governance, see Milton L. Mueller, "China and Global Internet Governance," in *Access Contested: Security, Identity, and Resistance in Asian Cyberspace,* eds. Ronald Deibert, John Palfrey, Rafal Rohozinski, and Jonathan Zittrain (Cambridge, MA: MIT Press, 2012).

[453] A variant of the IDAR model is *Shanzhai* (山寨), which is a business model aimed at producing cheap products good enough for the lower end of the Chinese market through imitation of foreign technology.

while indigenous innovation is not mentioned at all, the document does reiterate the importance of original innovation, integrated innovation, and re-innovation.[454]

The influence of indigenous innovation and techno-nationalism as strategic principles can be clearly felt in the policies that the Chinese authorities have formulated to promote its economic, industrial, and technological development.

Protectionism

The Chinese authorities view the protection of domestic science, technology, and industrial sectors from foreign competition as essential to ensure they are able to grow and thrive over the long term. Protection can be both direct and indirect in support of specific industries or firms. In most cases, however, the impact of a specific policy is not immediately measureable. In many cases, foreign companies do not disclose perceived violations or risks that result from Chinese state plans because they consider them part of the cost of doing business in China.

To avoid falling afoul of contravening international agreements and backlash from foreign firms and governments, Chinese protectionist policies are rarely found in state plans but are often implemented in tandem with them when they are issued. For example, in conjunction with the May 2015 rollout of the Made in China 2025 plan, the Chinese government announced a mandate that 90 percent of the machinery on the country's farms should be domestically produced by 2020.[455] This includes requiring domestic companies to have a 30 percent share of the high-end 200-plus horsepower market by 2020 and a 60 percent share by 2025.[456] Details of the mandate are still pending, but initial analyses of its impact on US and international players suggest that it will present a serious obstacle to their objective to penetrate the bottom 90 percent of China's market, where farms are extremely price sensitive and too small to afford high-end machinery.[457]

The Cultivation of Local and National Champions

An important plank of China's protectionist strategies is the building of domestic national champions. The MLP, SEI, Made in China 2025, and FYPs lay out specific industrial sectors that China aims to develop and which companies will receive greater attention from central and local policies. In the case of FYPs, it is common for provincial FYPs and other local policies to specifically include the names of favored companies (typically SOEs) in the plan.[458] While national-level plans avoid naming companies, it is not unusual for them to specify a target number of firms that should become internationally competitive.

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[454] "Proposal by the CPC Central Committee on Drawing Up the 13th Five-Year Program of National Economic and Social Development," Xinhua, November 3, 2015.
[455] "Will 'Made in China 2025' Displace International Farm Equipment Suppliers?" Smart Agriculture Analytics blog, June 3, 2015, http://smartaganalytics.com/blog/will-made-in-china-2025-displace-international-farm-equipment-suppliers/.
[456] Dominique Patton, "Machinery Makers Smell Opportunity as China's Farms Think Big," CNBC, October 1, 2015, http://www.cnbc.com/2015/10/01/reuters-america-machinery-makers-smell-opportunity-as-chinas-farms-think-big.html.
[457] "Will 'Made in China 2025' Displace International Farm Equipment Suppliers?"
[458] Andrew Szamosszegi and Cole Kyle, "An Analysis of State-Owned Enterprises and State Capitalism in China," US-China Economic and Security Review Commission, October 26, 2011, http://origin.www.uscc.gov/sites/default/files/Research/10_26_11_CapitalTradeSOEStudy.pdf.

In the newly emerging biomedical sector, for example, central and provincial authorities have targeted the establishment of national champions in their development plans. The national 12th FYP includes a specific goal to cultivate ten leading biomedical enterprises (*longtou qiye,* 龙头企业). Locally, the Shanghai municipal government in 2014 issued a Shanghai Biomedicine Industry Development Action Plan (2014−2017) (上海市生物医药产业发展行动计划) that set the goal of establishing one leading or "flagship" (*qijian,* 旗舰) biomedicine company with RMB 100 billion ($15.55 billion) in sales revenue and three companies with revenues of RMB 10 billion ($1.55 billion).[459] Shandong province's 12th FYP for biomedicine has similar goals.[460]

Local adaptations of national plans are often used to promote domestic companies at the cost of foreign competition. For example, Beijing's 12th Five-Year S&T Development Plan (北京市"十二五"科学技术普及发展规划纲要) stated its intention to implement the "Ten, Hundred, and Thousand Project (十百千工程)" for innovation companies by selecting more than 300 enterprises and providing special policy support to them. Its objective is to form a number of RMB 100 billion-level ($15.55 billion) globally competitive enterprises, RMB 10 billion-level industrial enterprises ($1.55 billion), and RMB 1 billion-level ($15.55 million) fast-growing enterprises.[461] In April 2010, the Zhongguancun National Innovation Demonstration Zone in Beijing announced its first list of selected enterprises under the Ten, Hundred, and Thousand Project, which included four RMB 100 billion-level ($15.55 billion) enterprises (Lenovo, Nokia, Peking University Founder Group, and Digital China), three RMB 50 billion-level ($7.77 billion) enterprises (Potevio, Tsinghua Tongfang, and Sinovel), and 116 lower-level enterprises.[462] Nokia was the only non-domestic firm selected. The inclusion of Nokia, however, seems to be a cynical move to portray the plan as one that can include foreign enterprises, when its actual purpose is to foster domestic enterprises.

In an earlier plan, Shanghai implemented the Shanghai Science and Technology Little Giant Project (上海市科技小巨人工程) in 2007 to provide financial support to unlisted medium and small high-tech enterprises. The support given typically lasted two to three years, and new enterprises were selected each year.[463] In 2014, only 2 out of 63 selected "Little Giant" enterprises were foreign companies (Solvay and Montage Technology); additionally, only 2 out of 109 selected "Little

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[459] Shanghai Office of the Science and Technology Commission, "上海市生物医药产业发展行动计划 (2014–2017年)" [Shanghai Biomedicine Industry Development Action Plan (2014–2017), http://www.stcsm.gov.cn/gk/ghjh/336089.htm.

[460] "山东省'十二五'生物医药发展规划" [Shandong Province 12th Five-Year Biomedicine Development Plan], Weifang City Major Project Management and Service Center website, May 22, 2013, http://mp963363.weifang.gov.cn/NewsView.asp?id=893.

[461] "北京市'十二五'时期高技术产业发展规划" [The 12th Five-Year Plan for the S&T Development of Beijing], Beijing Municipal Government website, December 2011, http://zhengwu.beijing.gov.cn/ghxx/sewgh/t1221393.htm.

[462] "中关村国家自主创新示范区首批'十百千工程'重点培育企业" [First List of Enterprises to Cultivate Under the "Ten, Hundred, and Thousand Project" in the Zhongguancun National Innovation Demonstration Zone], Zhongguancun National Innovation Demonstration Zone website, April 22, 2010, http://www.zgc.gov.cn/dt/rdyw/58253.htm.

[463] "关于印发《上海市科技小巨人工程实施办法》的通知" [Notice on Issuing the Implementation Plan on Shanghai Science and Technology Little Giant Project], Science and Technology Commission of Shanghai Municipality website, June 16, 2015, http://www.stcsm.gov.cn/gk/zcfg/gfxwz/fkwwj/341481.htm.

Giant" enterprises were foreign companies (McWong Environmental Technology and Tiger Electronics). Reasons for these foreign companies joining are unclear, but all four of the selected foreign enterprises were from the United States.[464] While there is no formal requirement that a company be domestic or part of a joint venture, it appears that the few foreign firms selected for the plan are merely token, and the primary emphasis is on promoting domestic companies.[465]

As a last example of local S&T plans favoring domestic companies, Guangdong Province's Intelligent Manufacturing Development Plan (2015–2025) (广东省智能制造发展规划) states that that the province aims to cultivate at least thirteen enterprises with annual revenue of more than 100 billion RMB ($15.55 billion) and about 125 enterprises with annual revenue of more than 10 billion RMB ($1.55 billion) by 2017.[466] Guangdong Governor Zhu Xiaodan has said that the development of the province's key enterprises should be a combination of developing SOEs, private enterprises, and foreign enterprises, but that the focus should be on private enterprises.[467] Similar policies exist in many other provinces and localities, often with the effect of favoring domestic companies over foreign companies. Indeed, while Chinese authorities are careful to include foreign enterprises in statements and plans, these statements and actions are largely intended to give the appearance of inclusiveness and equal treatment, but in practice the goal is to promote domestic enterprises.

Industry consolidation is a key mechanism used by Chinese authorities to promote national champions so that they can be competitive in global markets. This primarily occurs among SOEs but is expected to occur in other less state-controlled industries such as additive manufacturing as industries grow and also respond to market forces. As a CEO of a Chinese SOE recently stated, "Without size and strength, internationalization is fairly difficult."[468] This state-backed consolidation has been witnessed many times across almost all of China's high-tech industries. One such example is the 2013 acquisition of leading IC design and fabless semiconductor companies Spreadtrum and RDA Microelectronics by Tsinghua Unigroup to create China's largest microchip company. Since the merger, the group has received significant investments, including the purchase of a 20 percent stake by Intel. In July 2015, Tsinghua Unigroup announced that it was prepared to make a bid to purchase US memory chip maker Micron Technology for $23 billion, although the bid was never

[464] "关于公布 2014 年度科技小巨人工程立项名单并下达资助经费的通知" [Notice on the List of Enterprises of the S&T Little Giant Project of Year 2014], Science and Technology Commission of Shanghai Municipality website, June 24, 2014, http://www.stcsm.gov.cn/gk/ywgz/tzgs/gsgg/337317.htm.
[465] "市科委副主任陈杰问题解答" [Online Q&A with Chen Jie, vice director of Shanghai Committee of S&T], Shanghai Municipal Government website, March 26, 2013, http://chat.sh.gov.cn/Chatting/html/210/wtjd.html.
[466] "广东省人民政府关于印发《广东省智能制造发展规划（2015–2025 年）》的通知" [Guangdong Intelligent Manufacturing Development Plan (2015–2025)], People's Government of Guangdong Province website, July 23, 2015, http://zwgk.gd.gov.cn/006939748/201507/t20150729_595930.html.
[467] Hu Jian, Xie Sijia, Yue Zong and Fu Xin, "推动大型骨干企业发展" [Promoting the Development of Large-Scale Key Enterprises], 广州日报 [*Guangzhou Daily*], March 29, 2013, http://gzdaily.dayoo.com/html/2013-03/29/content_2196942.htm.
[468] Matthew Miller and Charlie Zhu, "Made in China: Beijing Plans New Wave of State Firm Consolidation," Reuters, March 11, 2015, http://uk.reuters.com/article/2015/03/11/uk-china-parliament-reform-idUK-KBN0M70LL20150311.

formalized due to concerns that it would not receive approval from the Committee on Foreign Investment in the United States.[469]

The high speed rail sector is one of China's leading prospects for becoming a major high-technology exporter. Its two principal corporations, China CSR Corporation (CSR) and China CNR Corporation (CNR) were consolidated into a single entity, China Railway Rolling Stock Corporation (CRRC) in 2015 to further bolster its chances of success. According to CRRC's general manager, the corporation aims to become the world's leading investment group in high-end manufacturing—an expansion of its focus on railways.[470] CRRC got off to a strong start when shortly after its establishment the Indonesian government announced that it had selected China over Japan for a contract to build a high speed railway system.[471] Many other sectors, including energy, shipbuilding, and telecommunications, are undergoing similar consolidations.

Promotion of National Standards

China's effort to set unique technology standards is an effective trade tool that helps reduce the royalty rates Chinese manufacturers pay to use foreign IP. Various state S&T plans directly encourage development of national standards. For example, the 12th FYP on advanced environmental protection encourages improvement of emission standards and environmental product standards. The 12th FYP for the satellite and application industry states the need to develop universal solar thermal regulations and standards. The 12th FYP for the new energy vehicle industry presses the need to establish and improve standards for new energy vehicles, charging technology, and facilities. The Made in China 2025 plan expresses the need to ensure the important role of enterprises in standards development, and to encourage and support enterprises, research institutes, and industry organizations to participate in international standards development.

An illustrative example of this occurred in 2012 after the WTO ruled that foreign payment processors such as Visa and MasterCard must be allowed to compete against China's state-owned Union Pay. Shortly after the ruling, the People's Bank of China instituted a China-specific technical standard different from the international payments standard that forced MasterCard and Visa to redesign their credit cards.[472] A more recent example is an announcement by China's State Administration of Press and Publication, Radio, Film and Television and MIIT of a new smart TV operating system, TVOS 2.0, and the requirement that indigenously developed operating systems must be used

[469] Eva Dou, "Who is Tsinghua Unigroup, the Firm Preparing a $23 Billion Bid for Micron," *Wall Street Journal*, July 14, 2015, http://blogs.wsj.com/digits/2015/07/14/who-is-tsinghua-unigroup-the-firm-preparing-a-23-billion-bid-for-micron/.

[470] "High-Speed Rail Maker CRRC Officially Established," Xinhua, September 28, 2015, http://en.people.cn/business/n/2015/0928/c90778-8956553.html.

[471] "China Wins Indonesia High-Speed Rail Project as Japan Laments 'Extremely Regrettable' U-Turn," *South China Morning Post*, September 29, 2015, http://www.scmp.com/news/asia/southeast-asia/article/1862459/china-wins-indonesia-high-speed-rail-project-japan-laments?page=all.

[472] USCC, "2015 Report to Congress of the US-China Economic and Security Review Commission" (Washington, DC: US Government Publishing Office, 2015), 175, http://origin.www.uscc.gov/sites/default/files/annual_reports/2015%20Annual%20Report%20to%20Congress.PDF.

for all set-top boxes throughout China. Operating systems for TVs and Internet TV devices not running TVOS were subject to exclusion.[473]

Some analysts are skeptical that China's push on elevating its national standards will have much of an impact on the global standards regime or force foreign companies to make concessions. Dan Breznitz and Michael Murphree argue that most Chinese standards are comparable or identical to international standards, which is the result of Chinese firms still being heavily reliant on foreign technology and their need to access overseas markets. To date, indigenous Chinese standards , such as TD-SCDMA, have not gained significant market support outside of China.[474] Still, China's practice of implementing indigenous standards is perceived as a challenge to US firms working in China. The American Chamber of Commerce (AmCham) in China issued the results of a survey in January 2016 that showed 42 percent of respondents in technology and other R&D intensive sectors believed that obtaining required licenses and an inability to participate in standard-settings were top challenges for foreign companies in China. In addition, 35 percent of the same respondents stated that requirements to comply with Chinese standards was a leading challenge.[475]

Technology Transfers

A major manifestation of China's efforts to become indigenously innovative is its active promotion of integrating technology from globally leading companies into domestic Chinese companies. This is in conjunction with efforts to cultivate national champions and to incubate locally developed and locally owned IPR. Over recent years, this has also become a leading point of concern among US companies doing business in China.

Upon its accession to the World Trade Organization (WTO) in December 2001, China committed to ensure the establishment and maintenance of a non-discriminatory regulatory and business environment for foreign firms. This included statements prohibiting setting requirements for technology transfer or use of local inputs as conditions for FDI approval. For example, permission for investment:

> would not be conditional upon performance requirements set by national or sub-national authorities, or subject to secondary conditions covering, for example, the conduct of research, the provision of offsets or other forms of industrial compensation including specified types or volumes of business opportunities, the use of local inputs, or the transfer of technology.[476]

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[473] "China to Require Internet TVs Use Homegrown Smart TV OS," *Hunan Daily,* December 25, 2015, http://www.marbridgeconsulting.com/marbridgedaily/archive/article/89286/china_to_require_internet_tvs_use_homegrown_smart_tv_os.

[474] Dan Breznitz and Michael Murphree, "The Rise of China in Technology Standards: New Norms in Old Institutions," US-China Economic and Security Review Commission, January 16, 2013, http://origin.www.uscc.gov/sites/default/files/Research/RiseofChinainTechnologyStandards.pdf.

[475] American Chamber of Commerce in PRC, "2016 China Business Climate Survey Report," January 2016, http://www.amchamchina.org/policy-advocacy/business-climate-survey/.

[476] *Protocol on the Accession of the People's Republic of China* (WT/L/432, November 23, 2001), Para. 203. See also US Chamber of Commerce, "China's Approval Process for Inbound Foreign Direct Investment: Impact on Market Access, National Treatment, and Transparency," November 11, 2012, https://www.uschamber.com/china's-approval-process-inbound-foreign-direct-investment-impact-market-access-national-treatment.

Enforcement of these agreements, however, has been difficult, and the experience of many US and other foreign firms since China's WTO accession differs in many respects from China's accession statements.

Treatment often varies by region or locality, but among the sources of increased barriers to US participation in the Chinese domestic market is language in state S&T plans such as the MLP and the SEI that implicitly encourage technology transfer, local use requirements, or creation of national champions to achieve stated goals of technological development and the creation of indigenous innovation. It should be noted, however, that Chinese leaders repeatedly emphasize that domestic companies are not favored over foreign companies. For example, Wen Jiabao, at the Summer Davos Forum in September 2012, stated that foreign-invested enterprises operating in the SEIs would be treated the same as Chinese companies.[477]

Over the past decade, however, China has increasingly used access to its domestic market to selectively coerce technology companies into transferring technology to local companies. While no specific requirements for foreign companies to share or expose their technologies for access to the Chinese market are contained in the MLP, the US-China Business Council has stated that after China's access to the WTO, the policy turned from explicit to implicit.[478] The MLP does encourage multinational companies to establish R&D institutes in China to enhance international technology cooperation and communication. China's former Minister of Commerce Chen Deming stated that prior to entering WTO, China cancelled stipulations of forced technology transfer, and that any current technology transfers or technology cooperation are companies' independent decisions. Chen said that the Chinese government does not make it a precondition for access to the Chinese market.[479]

The Commission on the Theft of American Intellectual Property, however, has argued that there has been an increase in theft and compulsory technology transfer.[480] China's SEI plan further supports technology transfer to Chinese companies in return for incentives, such as financial subsidies, to operate locally. A 2011 McKinsey report on the SEI initiative stated that "[f]oreign companies must bring advanced technology and be seen as trusted partners for local innovation."[481]

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[477] US–China Business Council, "China's Strategic Emerging Industries: Policy, Implementation, Challenges, and Recommendations," March 2013, https://www.uschina.org/sites/default/files/sei-report.pdf.

[478] Thomas Holmes, Ellen McGrattan, and Edward C. Prescott, "Quid Pro Quo: Technology Capital Transfers for Market Access in China," VoxEU.org, November 8, 2013, http://www.voxeu.org/article/technology-transfer-chinese-markets.

[479] "陈德铭就所谓'强制性技术转让'等问题接受采访" [Chen Deming Was Interviewed and Responded to the So-Called "Forced Technology Transfer" Question], PRC Central Government website, February, 2, 2012, http://www.gov.cn/gzdt/2012-02/09/content_2062548.htm; "Technology Transfer Not Precondition for Market Access: Minister," Xinhua.net, February 9, 2012, http://news.xinhuanet.com/english/china/2012-02/09/c_131401376.htm.

[480] Commission on the Theft of American Intellectual Property, "The IP Commission Report: The Report of the Commission on the Theft of American Intellectual Property," National Bureau of Asian Research, May 2013, http://www.ipcommission.org/report/IP_Commission_Report_052213.pdf, 17.

[481] Guangyu Li and Jonathan Woetzel, "What China's Five-Year Plan Means for Business," McKinsey Insights and Publications, July 2011, http://www.mckinsey.com/insights/economic_studies/what_chinas_five-year_plan_means_for_business.

The policy was stated succinctly in a 2013 US Trade Representative report:

> In some cases, central, provincial, and local level Chinese agencies inappropriately require or pressure rights holders to transfer IPR from foreign to domestic entities. Sometimes guided by government measures or policy statements intended to promote indigenous innovation and the development of strategic industries, government authorities deny or delay market access or otherwise condition government procurement, permissions, subsidies, tax treatment and other actions on IPR being owned or developed in China, or licensed to a Chinese entity.[482]

While these cases appear to occur regularly, in overall terms they are the exception rather than the rule. A 2014 US−China Business Council survey revealed that technology transfer does not affect the majority of US companies seeking to enter Chinese market to do business.[483] Out of the 20 percent of companies that were asked to transfer technology, however, one-third of the companies reported a form of compulsory technology transfer, where they had to comply with a technology transfer request even when they deemed it unacceptable. Furthermore, only a small percentage of companies reported that the technology would be controlled by a Chinese entity.[484] It is difficult to assess the reliability of this number, however. A survey by another ICT-related industry association of experiences from its member companies in China received only a couple of nondescript responses even after many members had informally issued complaints of mistreatment in their China operations by the Chinese government.[485] The majority of companies worry that publicizing complaints will increase the difficulties of doing business in China.

Shareholder concerns also prevent many firms from reporting hardships in operating in China. In a January 2016 report by AmCham China, 53 percent of respondents from technology and other R&D intensive sectors reported that their top challenge to succeeding in China is inconsistent regulatory interpretation and unclear laws. 44 percent also stated that increasing Chinese protectionism was a challenge.[486]

Policies dictating the necessity of technology transfers in exchange for domestic incentives have also been reported at the sub-national levels. The Shanghai government's SEI fund is a carve-out of a larger indigenous innovation and high-tech special fund that requires local IP ownership and local legal presence to qualify for funding. In addition, wholly foreign-owned R&D centers may not be approved for SEI research projects unless they independently own the IPR.[487]

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[482] Office of the United States Trade Representative (USTR), "2013 Special 301 Report," May 2013, 32, https://ustr.gov/sites/default/files/05012013%202013%20Special%20301%20Report percent202013 percent20Special percent20301 percent20Report.pdf.
[483] US-China Business Council, "USCBC 2014 China Business Environment Survey Results: Growth Continues Amidst Rising Competition, Policy Uncertainty," https://www.uschina.org/reports/uscbc-2014-china-business-environment-survey-results.
[484] US-China Business Council, "USCBC 2014 China Business Environment Survey Results."
[485] Interview with high-tech industry representative, Washington, D.C., January 14, 2016.
[486] AmCham China, "2016 China Business Climate Survey Report."
[487] US-China Business Council, "China's Strategic Emerging Industries."

Caution should be taken in associating each individual business decision as resulting from top-down pressure outlined in state plans or imposed by government regulators. In official dialogues with US policymakers, Chinese leaders have sought to clarify "that technology transfer and technological cooperation shall be decided by businesses independently and will not be used by the Chinese Government as a pre-condition for market access," and "to treat and protect IPR owned or developed in other countries the same as domestically owned or developed IPR." At the 23rd US−China Joint Commission on Commerce and Trade in 2012, China "reaffirmed that technology transfer and technology cooperation are the autonomous decisions of enterprises" and further pledged that, "if departmental or local documents contain language inconsistent with the above commitment, China will correct them in a timely manner."[488]

The request to transfer technology to Chinese companies appears to be a reasonable demand from the standpoint of some firms in return for increased opportunities to build their business operations in China. For example, while no technology transfer agreement was mentioned in Boeing's decision in September 2015 to build a B-737 jet completion and delivery center in China, its CEO stated that its investment "could become a catalyst to growing the business even more" and expressed that there would be "dire consequences" if Boeing chose not to work with China.[489]

Other leading US technology and industrial firms have entered into major agreements in the past few years to provide technology transfers in exchange for expanded market access. In 2012, IBM signed multiple deals with Chinese companies that transferred software and hardware blueprints to local vendors that would allow them to produce versions of its Power8 processor and build and sell severs that would compete with IBM products. Among these companies is Inspur, a Chinese leader in server manufacturing and software development.[490] General Electric attracted attention in 2011 when it entered a deal with AVIC to transfer avionics technology for the development of the country's C919 commercial airliner.[491]

National security concerns are intensifying Chinese government demands for access to highly sensitive proprietary information from foreign companies, in part because of NSA contractor Edward Snowden's revelations of the scale, sophistication, and reach of US technical espionage. The Chinese authorities are drawing up sweeping national security, cybersecurity, and foreign investment laws and regulations that require national security reviews and only permit the use of technology that is "secure and controllable." This could mean that foreign technology companies are required to provide back-door access to their systems or encryption keys, or even transfer source code.[492]

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[488] USTR, "2013 Special 301 Report," 32.
[489] Dominic Gates, "Boeing Chief Defends China 737 Center, Unveils 300 Jet Orders," *Seattle Times*, September 23, 2015, http://www.seattletimes.com/business/boeing-aerospace/boeing-agrees-to-open-737-center-in-china-inks-300-new-jet-orders/.
[490] David Wolf, "Why Buy the Hardware When China Is Getting the IP for Free?" *Foreign Policy*, April 24, 2015, http://foreignpolicy.com/2015/04/24/ibm-technology-transfer-china-virginia-rometty-strategy-lenovo-huawei-it.
[491] Howard Schneider, "GE 'All In' on Aviation Deal with China," *Washington Post*, August 22, 2011, http://www.washingtonpost.com/business/economy/ge-all-in-on-aviation-deal-with-china/2011/07/17/gIQAg-PmTXJ_story.html.
[492] Paul Mozur, "Jitters in Tech World Over New Chinese Security Law," *New York Times*, July 2, 2015.

In October 2015, IBM became the first major US technology company to provide Chinese authorities with its source codes, although only in a controlled IBM environment "to ensure that no software source code is released, copied, or altered in any way."[493]

Catalogues

A key role that state agencies play in guiding economic, industrial, and technological development is to act as gatekeepers to regulate the engagement between the Chinese economy and the outside world. One of the most important tools for this task is the issuance of detailed catalogues (目录) that define what activities are encouraged, restricted, or prohibited. They are essentially "planning documents that list key industries and products that are favored by the central government."[494] They are often issued as attachments or post-hoc supplements to state plans and programs. There is, for example, a catalogue for key products and services for the SEI plan and a catalogue for the importation of encouraged technologies and products that is associated with the MLP.[495]

The NDRC is the primary government agency responsible for these catalogues, which reflects its historical role as a highly interventionist central planning agency. The commission coordinates closely with other state entities in the formulation of these documents. In the foreign investment and technology domains, its principal partners are MOFCOM and MOF with input also from MOST and MIIT.

An important catalogue regulating foreign participation in China's industrial economy is the Catalogue for the Guidance of Foreign Investment Industries (外商投资产业指导目录), which determines the nature of foreign involvement in specific industries. The two most recent catalogues were issued in 2011 and 2015.[496] In addition to encouraging or restricting foreign investment, the catalogue also provides technological requirements. For example, "ground and water effect aircraft manufacturing and UAV and aerostat design and manufacturing" is encouraged as an investment area for foreign companies, but a Chinese entity must hold 51 percent or more of the equity (*zhongfang konggu,* 中方控股). In contrast, "ship low- and medium-speed diesel engine design and components" required foreign firms to be part of a joint venture in the 2011 Catalogue, but this requirement was removed in the 2015 Catalogue. In cases where China has no bargaining power but wants the technology, it will encourage 100 percent foreign ownership since that is the only choice. An example of an "encouraged" investment with no joint venture or equity requirements is "IC design, manufacturing of 28 nm and below large-scale digital IC, manufacturing of 0.11-micron and below analog and mixed signal IC, manufacturing of MEMS and compound semiconductor IC, and BGA, PGA, CSP, MCM, and other advanced packaging and testing." This category does not specify any joint venture or Chinese controlled entity requirement. The Catalogue of Encouraged Technologies

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[493] Eva Dou, "IBM Allows Chinese Government to Review Source Code," *Wall Street Journal,* October 16, 2015, http://www.wsj.com/articles/ibm-allows-chinese-government-to-review-source-code-1444989039?alg=y.

[494] Szamosszegi and Kyle, "Analysis of State-owned Enterprises and State Capitalism in China," 63.

[495] US-China Business Council, "China's Strategic Emerging Industries."

[496] For the 2011 catalogue, see National Reform and Development Commission and Ministry of Commerce, "外商投资产业指导目录 (2011 年修订)" [Catalogue for the Guidance of Foreign Investment Industries (2011 Revision)], December 24, 2011, http://www.mofcom.gov.cn/article/b/f/201112/20111207907901.shtml. For the 2015 catalogue, see National Reform and Development Commission and Ministry of Commerce, "外商投资产业指导目录(2015 年修订)" [Catalogue for the Guidance of Foreign Investment Industries (2015 Revision)], March 10, 2015, http://www.sdpc.gov.cn/zcfb/zcfbl/201503/W020150402620481787669.pdf.

and Products for Import is the principal catalogue for the regulation of investment in S&T (see Appendix B).

"Going Out" Strategy and Chinese Foreign Direct Investment to the United States

An important goal of China's technology, industry, and energy development plans is to be globally competitive. The MLP emphasizes the need to "support enterprises in their going out" efforts, which is through promoting export of high-technology products and encouraging firms to establish R&D centers or industrialization bases overseas. The Made in China 2025 plan encourages support of small and medium enterprises to "go out and bring in" (走出去和引进来).[497] It also promotes the use of "two types of resources and two markets" (两种资源、两个市场), which refers to using both domestic and foreign resources and domestic and global markets to create a more proactive opening up strategy. Numerous other plans contain similar language.[498]

In the State Council's "Internet Plus" Action Guidelines (国务院关于积极推进"互联网+"行动的指导意见) issued in July 2015, Internet companies were encouraged to cooperate with manufacturing, finance, and information communication companies to be able to "band together and go abroad" (抱团出海).[499] According to the guidelines, these companies should help each other in foreign M&A deals, joint operations, and the establishment of subsidiaries to open up global market share, promote international cooperation, and establish cross-border industrial chains. It further asked for support from industry associations, alliances, and companies to promote Chinese technology and standards in international markets.

To support foreign investment by Chinese companies, state plans also outline needs to provide financial and regulatory support. In the Made in China 2025 plan, the Export-Import Bank of China and the China Development Bank are encouraged to increase loans. The plan also pushes the exploration of new channels including industrial funding and state-owned capital gains (of which portions are handed back to the government) to support industries such as high speed rail, automotive, and construction in overseas investment and M&A.[500]

This international push is manifested in the increasing levels of Chinese FDI globally. Chinese corporate FDI to the United States grew from $2 billion from 46 transactions in 2005 to $15.7 billion from 171 transactions in 2015 (Figure 13). Cumulatively, China has invested $63.3 billion

[497] "国务院关于印发《中国制造 2025》的通知" [The State Council's Notice on Issuing "Made in China 2025"], Ministry of Finance website, May 8, 2015, http://www.mof.gov.cn/zhengwuxinxi/zhengcefabu/201505/t20150519_1233751.htm.

[498] For example, China's Energy Development Strategy Action Plan (2014–2020) calls for increased exports of nuclear power. "国务院办公厅关于印发能源发展战略行动计划 (2014–2020 年) 的通知" [The State Council's Notice on Issuing the Energy Development Strategy Action Plan (2014–2020)], Ministry of Land and Resources website, June 7, 2014, http://www.mlr.gov.cn/xwdt/jrxw/201411/t20141119_1335668.htm.

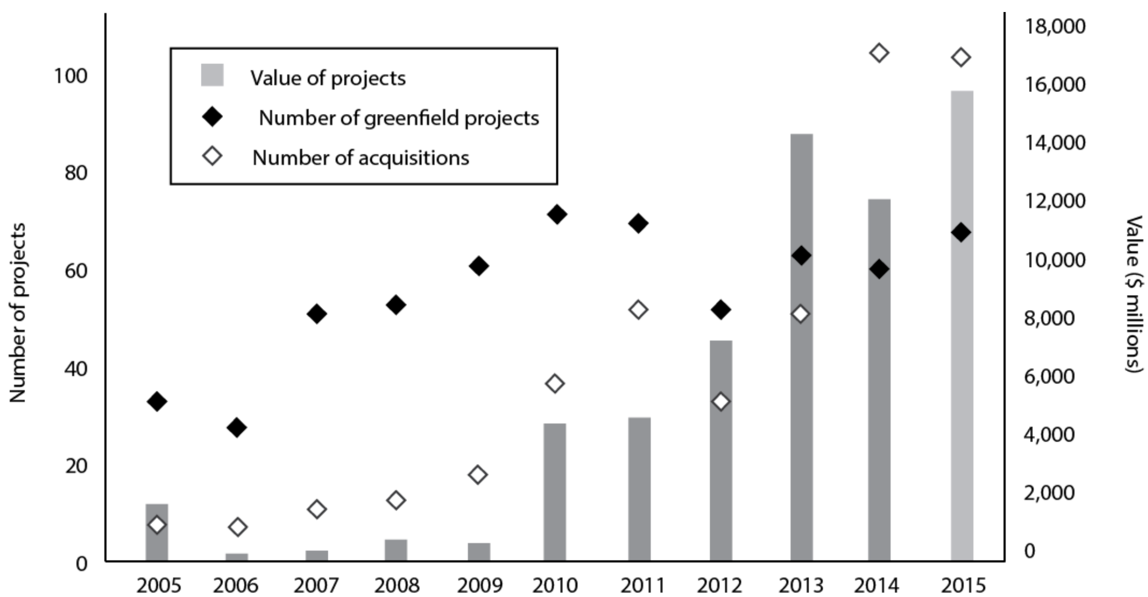
[499] "国务院关于积极推进"互联网+"行动的指导意见" [The State Council's Guidance on the "Internet Plus" Action], PRC Central Government website, July 4, 2015, http://www.gov.cn/zhengce/content/2015-07/04/content_10002.htm.

[500] "The State Council's Notice on Issuing "Made in China 2025."

in the United States from 2000 to 2015.[501] This accounts for a relatively small share of total Chinese global FDI, although the value of Chinese FDI in the United States did exceed any other single country (see Figure 14).[502] It is difficult to pinpoint exact S&T plans driving particular FDI transactions. Chinese state S&T plans, however, consistently emphasize Chinese companies' investment abroad and the push to create a regulatory environment conducive to this drive. This undoubtedly has an influence on the ability and ambitions of Chinese enterprises to invest globally.

Chinese firms are also attracted to the United States for numerous market-oriented reasons. This includes the opportunity to acquire advanced technology, market access, localization of supply chains, learning US industrial techniques and advanced production processes, ability to circumvent trade barriers, and in some cases lower costs of certain kinds of skilled labor and land, stable and cheap energy prices (particularly for the petrochemical industry), and lower cost of raw materials and electricity.[503]

Figure 13. Chinese FDI transactions in the United States



Source: Adapted from Figure 1 in Thilo Hanemann and Cassie Gao, "Chinese FDI in the US: 2015 Recap, January 19, 2016, http://rhg.com/notes/chinese-fdi-in-the-us-2015-recap.

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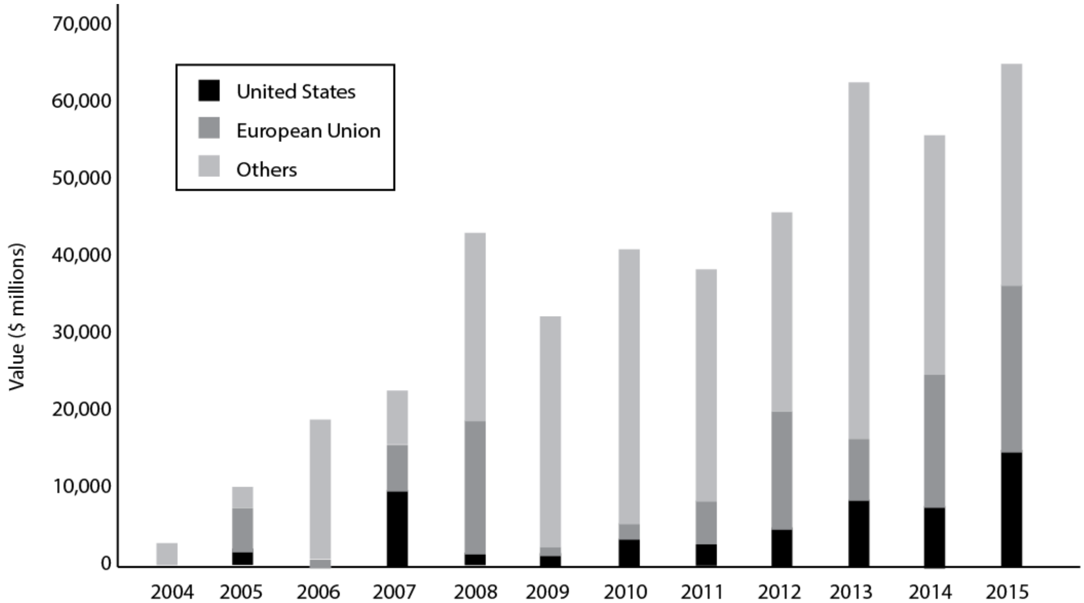
501 Rhodium Group, "China Investment Monitor," accessed January 28, 2016, http://rhg.com/interactive/china-investment-monitor.

502 Remarks of Daniel H. Rosen during live webcast of 2015 CHINA Town Hall, hosted by National Committee on United States-China Relations, October 5, 2015, http://livestream.com/accounts/15425177/events/4391175.

503 Iacob Koch-Weser and Garland Ditz, "Chinese Investment in the United States: Recent Trends in Real Estate, Industry, and Investment Promotion," US-China Economic and Security Review Commission Staff Research Report, February 26, 2015, 16−18, http://www.uscc.gov/sites/default/files/Research/Ch%20invt%20paper percent20invt percent20paper_2%2026%2015 percent2026 percent2015.pdf. On market access see Jim Kinney, "Chinese CRRC USA Rail Corp. Breaks Ground on $95 Million Subway Car Factory in Springfield," Mass Live, September 3, 2015, http://www.masslive.com/business-news/index.ssf/2015/09/chinese_crrc_usa_rail_corp_breaks_ground.html. On skilled labor and land, see Daniel H. Rosen and Thilo Hanemann, "Chinese Direct Investment in California," Asia Society Special Report (October 2012), 32, http://asiasociety.org/files/pdf/Asia_Society_China_CA_Investment_Report_FINAL.pdf.

Figure 14. Completed Chinese outbound M&A transactions by target region



Source: Adapted from Figure 3 in Thilo Hanmann and Cassie Guo, "China's Global Outbound M&A in 2015," Rhodium Group, January 4, 2016, http://rhg.com/notes/chinas-global-outbound-ma-in-2015.

The implications for US competitiveness from Chinese FDI appear to be largely positive. New York-based advisory firm Rhodium Group estimates that if the United States maintains its average share of 17 percent of global FDI flows achieved during the first decade of the twenty-first century, it could expect between $100 billion to $400 billion in new Chinese M&A and greenfield investments over the decade from 2010 to 2020.[504] This investment brings large numbers of jobs to the United States. In 2013, more than 80,000 Americans in the United States were on Chinese corporate payrolls, which was a sharp increase from 15,000 in 2010.[505] Increased Chinese FDI would further support jobs in the United States. Additional jobs are created indirectly during construction of facilities and through the creation of supply chains. The Rhodium Group further estimates that by 2020 the number of direct jobs for Americans on Chinese corporate payrolls could increase to 200,000−400,000.[506]

The 'One Belt, One Road' Strategy

A new central component of China's "going out" strategy is its "One Belt, One Road" (OBOR) strategy. The strategy was introduced by Xi Jinping in 2013 and refers to the dual strategies of the "New Silk Road Economic Belt" and the "21st Century Maritime Silk Road." The plan aims to connect China with countries in Asia, Africa, and Europe to better integrate China into the regional

[504] Rosen and Hanemann, "Chinese Direct Investment in California," 22.

[505] Greenfield FDI refers to investment where a company invests in a foreign country by constructing facilities or infrastructure from the ground up. Daniel H. Rosen and Thilo Hanemann, "New Realities in the US-China Investment Relationship," April 2014, 9, http://rhg.com/wp-content/uploads/2014/04/RHG_New-Realities_29April2014.pdf.

[506] The National Committee on US-China Relations and Rhodium Group, "New Neighbors: Chinese Investment in the United States by Congressional District," May 2015, 7–8, https://www.ncuscr.org/sites/default/files/Chinese-FDI-in-US_Full-Report-2015-NCUSCR_0.pdf.

economy and to strengthen its influence in the Asia-Pacific region. The strategy quickly received strong support within China, and in March 2015 it was upgraded to a national strategy in a joint guidance issued by NDRC, MOF, and MOFCOM.[507]

Funding support for the OBOR strategy has been significant. In November 2014, China announced a contribution of $40 billion to set up the Silk Road Infrastructure Fund.[508] The first investment from the fund was for the Karot hydropower project in Pakistan with an investment of $1.65 billion.[509] Additionally, the Asian Infrastructure Investment Bank has authorized $100 billion in capital, which is expected to give strong support to OBOR investment projects.[510] From the announcement of the strategy in late 2013 to mid-2015, the China Development Bank and China Export-Import Bank together made 67 overseas loan commitments, the majority of which were in countries defined in the OBOR strategy.[511] Altogether, by July 2015, Chinese enterprises had invested a cumulative total of $8.59 billion in 48 OBOR countries and also took on contracted infrastructure projects in 60 countries, signing more than 1,700 contracts that total to nearly $49.5 billion.[512]Exact details are not known, but it is likely that a large ratio of this investment comes from re-categorizing existing projects under the OBOR initiative.

Strong Chinese government support for the initiative has the potential to divert some FDI otherwise directed to the United States to OBOR countries. To date, however, M&A activity in OBOR countries did not see a substantial increase after the announcement and launch of the OBOR initiative. Rhodium Group assesses this to mean that either there is a longer time lag for the OBOR policy to translate into deals or that investors prefer greenfield FDI, loans, and other modes to gain exposure to those markets.[513]

The Chinese government hopes to use the OBOR strategy to address and assuage concerns about overcapacity concerns in many Chinese industrial sectors. This includes excess capacity of more than 20 percent in traditional manufacturing sectors such as iron and steel, cement, aluminum, glass and shipbuilding.[514] Chinese companies are directing much of this overcapacity to countries

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[507] Ernst and Young, "Navigating the Belt and Road: Financial Sector Paves the Way for Infrastructure," August 2015, 6, http://www.ey.com/Publication/vwLUAssets/EY-navigating-the-belt-and-road-en/$FILE/EY-navigating-the-belt-and-road-en.pdf.

[508] Paul Carsten and Ben Blanchard, "China to Establish $40 Billion Silk Road Infrastructure Fund," Reuters, November 8, 2014, http://www.reuters.com/article/2014/11/08/us-china-diplomacy-idUSKBN0IS0BQ20141108.

[509] Ting Shi and Natalie Obiko Pearson, "China Picks Pakistan as First Stop on $40 Billion Silk Road," *Bloomberg News*, April 21, 2015, http://www.bloomberg.com/news/articles/2015-04-21/china-picks-pakistan-dam-as-first-stop-on-40-billion-silk-road.

[510] "China Follows Silk Road in Search for Land of Fast Growth," *Bloomberg News*, April 14, 2015, http://www.bloomberg.com/news/articles/2015-04-14/china-follows-the-silk-road-in-search-for-land-of-fast-growth.

[511] James Kynge, "Chinese Overseas Lending Dominated by One Belt, One Road Strategy," *Financial Times*, June 18, 2015, http://www.ft.com/intl/cms/s/3/e9dcd674-15d8-11e5-be54-00144feabdc0.html#axzz3pPhgYFDC.

[512] "'一带一路'侧重基础设施建设,利好工程机械" ['One Belt, One Road' Focuses on Infrastructure Construction, Good for Engineering and Machinery], 中国机械专家网 [China Machinery Experts Network], September 16, 2015, http://www.cccme.org.cn/news/content-255728.aspx.

[513] Hanemann and Guo, "China's Global Outbound M&A in 2015."

[514] "中金: 一带一路扩影响提内需 利好五大产业" [CICC: 'One Belt, One Road' Expands its Influence and Increases Demand, Benefits Five Major Industries], 上海证券报 [*Shanghai Securities News*], December 17, 2014, http://finance.sina.com.cn/stock/hyyj/20141217/014021092707.shtml.

within the catchment area of the OBOR strategy. For example, PricewaterhouseCoopers estimates that more than $250 billion of infrastructure projects from railways to power plants have been contracted since the 2013 announcement.[515] Chinese provincial government work reports put the investment value of OBOR infrastructure construction to date at a much higher figure of $1.04 trillion.[516] Implications for the United States from a reduction in Chinese overcapacity include rising prices for Chinese industrial goods, such as steel and aluminum, but also increased competition for US firms.

While the projects are certainly significant, economists such as David Dollar of the Brookings Institution doubt that the impact of these investments will be large enough to be macro-economically meaningful.[517] Regardless of the size of the impact, however, China so far is showing its full commitment to advancing the OBOR strategy, and has already used it to increase investment and ties with its neighboring countries.

Analytical Framework for Assessing Impact on US Economic Competitiveness

In carrying out the case studies, a general analytical template was developed that can be applied across different sectors to assess the impact of Chinese state plans on US economic competitiveness. In examining the multitude of factors that shape how US and Chinese companies compete, collaborate, and interact in their own markets, in each other's markets, or at the global level, this framework focuses on three components: 1) technology levels and trajectories of US and Chinese firms; 2) industry market conditions; and 3) government policy measures.

Technology Levels

Technology levels refer to the progress and nature of technology development in a country. As many industries are becoming increasingly globalized, it is sometimes difficult to disaggregate businesses and operations at a national level. China's technology goals, however, make it clear that it aims to cultivate a broad field of domestic companies that promote indigenously developed technology and are internationally competitive.

Any interactions between Chinese and US companies will be heavily influenced by their relative levels of technology development. For example, industries in which Chinese companies technologically lag behind their US competitors are more likely to solicit participation of US companies in the Chinese market, encourage joint ventures, and utilize a quid pro quo strategy of trading market access for technology. These same companies may also seek to invest in advanced economies, often through M&A, to access higher levels of technology, talent, and markets. Conversely, industries in which Chinese companies lead or match their US counterparts may be more likely to seek investment in the US market to establish distribution channels or further tap into US expertise. They may also seek to attract leading US companies to China to form partnerships or joint ventures to further develop their technology. The behavior of companies is generally more nuanced than

[515] Brenda Goh and Qing Gui Koh, "China's 'One Belt, One Road' Looks to Take Construction Binge Offshore," Reuters, September 6, 2015, http://www.cnbc.com/2015/09/06/reuters-america-chinas-one-belt-one-road-looks-to-take-construction-binge-offshore.html.
[516] "Navigating the Belt and Road: Financial Sector Paves the Way for Infrastructure," EY, Aug 2015, http://www.ey.com/Publication/vwLUAssets/EY-navigating-the-belt-and-road-en/$FILE/EY-navigating-the-belt-and-road-en.pdf, 7.
[517] David Dollar, "China's Rise as a Regional and Global Power Enters a New Phase," Brookings Institution, July 20, 2015, http://www.brookings.edu/blogs/order-from-chaos/posts/2015/07/20-china-aiib-one-belt-one-road-dollar.

this, and the dynamics that play out between the various industry actors will differ from industry to industry.

For this report, technology levels are not precisely measured by metrics such as maturity of technology or months or years expected for one country to catch up to the other. Indeed, measurements of technology levels and the technological gap between the United States and China are imprecise and difficult to find. Moreover, constructing a metric to compare levels and gaps across industrial sectors poses difficulty due to varying speeds of technological development and differing inputs into the innovation process within each industrial sector.

Market Characteristics

A wide variety of market conditions can be predictive of the level or immediacy of impact that China's push forward in various industries will have on US firms. These factors include: 1) the market share of US and Chinese firms in each country's economy and also in the global market; 2) the growth of the Chinese market and demand; 3) the levels and types of current investment in each country; 4) the identity of leading actors from each country; and 5) the availability of financial support through state funding or capital markets. Export volumes, particularly US exports to China, also are important in considering whether a strengthened position by Chinese companies in their domestic market will crowd out demand of foreign products.

Determining the nature of future foreign direct investment (FDI) can reveal implications of Chinese companies' involvement in the US market. For example, Chinese companies that enter the US market in order to access its distribution channels and customer base will impact local companies differently than a company seeking entry into the US market in order to increase production efficiency and then re-export its products to external markets. Similarly, the extent to which a US-invested Chinese company would promote the development of local supply chains also impacts the levels of employment, technology diffusion, and other benefits it may bring to the US economy.

Within the Chinese market, access for US firms is often determined by policy measures implemented by national and local authorities. These can be explicit or implicit and include many of the issues discussed in the previous section, such as protectionism, support of national champions, and promotion of national standards. In addition to these areas, many other domestic market factors may affect the ability of US companies to enter the market and, in turn, support or hinder the implementation of Chinese state-led policies. They include the concentration of market share in the Chinese market, location of supply chains, reliance on imports, technology licenses from foreign multinationals, or technology otherwise held by foreign companies.

Policy Measures

The Chinese government led by Li Keqiang has expressed intent in the past several years to allow the market to play a more "decisive role" in the economy.[518] However, government-led policies still pervade every high-tech and industrial sector within China. These policies, regulations, and other "soft" factors promote or hinder the innovation environment and influence the ability of US companies to take advantage of opportunities created through China's state plans as well as challenges they may encounter. Indeed, not all policy objectives will be achieved. However, the stated

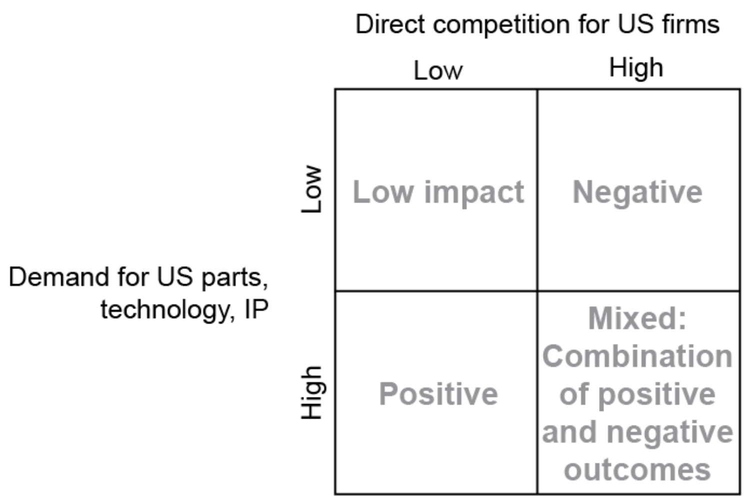
[518] Bob Davis, "Beijing Endorses Market Role in Economy," *Wall Street Journal*, November 12, 2013, http://www.wsj.com/articles/SB10001424052702304644104579193202337104802.

objectives in state plans provide a strong indication of the level of government support for a particular industry. This central-level support creates pressure and incentives for subnational actors to likewise promote emphasized sectors and industries.

Implications for US Economic Competitiveness

These three components—technology levels, market characteristics, and policy measures—provide context for evaluating the impact that China's state-led plans may have on US economic competitiveness. It should be pointed out that this analysis offers broad indicators and trends of the impact and not does attempt to provide precise or nuanced judgements about the size or timelines. The analysis positions China's impact on US competitiveness along two dimensions to create a matrix of four possible outcomes (see Figure 2, repeated here for the reader's convenience). The dimensions are direct competition for US firms and demand for US parts, technology, and IP.

Figure 2. Matrix of possible outcomes on US competitiveness from Chinese industries



Direct Competition for US Firms

The level of direct competition between US and Chinese firms is a significant element determining the effect that Chinese policies could have on the US economy. The prime goal of Chinese state S&T and industrial plans is to upgrade the competitiveness of Chinese firms. To determine the effect on the United States, an examination of the areas of competition is necessary. The preceding sections on relative US–China technology levels and market characteristics provide the context to determine whether a more competitive Chinese industry will impact US firms directly and US production and workforce levels more broadly.

The discussion of Chinese policy measures supports examination of what segments of an industry Chinese authorities are targeting for government support. In most policies, Chinese innovation strategy aims to create national champions that are able to compete internationally at the leading edge. This will often increase direct competition with US firms. In some cases, however, US firms do not lead in the industry or are ahead in different industry segments than those being targeted by Chinese state plans. The impact of China's policies in these areas will consequently be much less.

Chinese state plans will most directly affect US firms seeking to operate in the Chinese market. Increased competition comes from a variety of sources: 1) consolidation of existing competitors; 2) acquisition by Chinese firms of leading foreign technology and global talent; 3) increased local protectionism; 4) provision of government subsidies to local industry; and 4) creation of new Chinese companies with strong state support. All of these sources can be traced back to state policies, although market forces will also contribute to this competition. Increased competition resulting from these factors will not be limited to within China's borders. As Chinese companies globalize their supply chains and other operations, the impact of China's state policies will be felt globally.

Direct competition between US and Chinese firms alone does not mean that increased Chinese investment will negatively impact US firms. In some cases, US and Chinese firms could be in direct competition, but increased Chinese investment could displace other global competitors rather than US firms in ways that might prove advantageous to US firms. In other cases, Chinese FDI in the US economy could also have positive impacts by spurring creation of supply chains that support local workforces and boost local economies. Both of these scenarios are certainly possible, and Chinese FDI in the United States is indeed increasing, although at a limited level.

Demand for US Parts, Technology, and Intellectual Property

The second dimension of the outcomes matrix is demand for US parts, technology, and intellectual property. This refers specifically to demand within China. Demand influences the quantity that Chinese industries or consumers purchase of US goods and services, whether imported from the US or produced by US firms in China. Demand defined here includes both the total size of China's consumption capacity of goods and services and also the demand for goods and services from US suppliers relative to demand for the same goods and services from Chinese suppliers. This second part can also be referred to as the supply ratio between US and Chinese suppliers for China's market demand. Consequently, the two factors influencing the impact on US economic competitiveness as China upgrades its high-tech industry are: 1) the rate at which Chinese market demand grows; and 2) the rate at which Chinese suppliers replace current US suppliers.

Demand for US parts, technology, and IP can be influenced by many factors. The most important of these factors related to Chinese government policies or actions taken by Chinese firms in the following ways: 1) protectionist policies; 2) procurement policies of domestic suppliers; 3) technology standards that require customization to the Chinese market; 4) trade barriers; 5) general investment environment for foreign firms; 6) price changes of competing Chinese products; and 7) technology levels of Chinese firms. Demand may also be affected by factors controlled by US firms and the US government, such as: 1) price changes of US products; 2) technology levels of US firms; 3) export controls; and 4) corporate tax policies. Other factors are outside the direct influence of either the United States or China but also directly impact demand. Primary among these factors is the price of oil, which primarily influences the cost of shipping goods overseas.

In industries where current demand for US parts, technology, and IP is high, US firms bear a much larger impact from changes in the international environment and improved positions of their competitors. These industries typically are underdeveloped in China and rely heavily on imported US technology, licenses from US firms, or the operation of multinational companies in China. The impact of state-led policies aimed at upgrading Chinese technology on these industries will be negative. As supply of upgraded Chinese technology increases, domestic suppliers increasingly will be able to fulfill domestic demand for US technology. This will be particularly noticeable in sectors where US firms lead in technology and market share.

The increasing size of the Chinese market also does not directly translate into an increase in demand for US parts, technology, and IP. Chinese government policies, to the contrary, can overrule market forces to favor domestic Chinese companies and supplant US suppliers. While the Chinese economic pie is getting larger, US firms may not share in the benefits that come from this development.

In industries where US firms do expand their presence, the potential implications for US economic competitiveness and for US production and its workforce are mixed. The profitability of US firms in such industries likely will increase. An expanding presence in China, however, could draw other segments of the value chain away from domestic US locations as suppliers and consumers seek to be closer to major centers of production and market demand. This, of course, is dependent on many factors, including the extent to which supply chains are globalized, but would in general have a negative effect on US production and workforce levels.

Possible Outcomes

The combination of the level of direct competition for US firms and demand for US parts, technology, and IP provide a set of possible outcomes resulting from an upgrading of Chinese industry. This analysis focuses in particular on effects of China's state-led policies on increasing the competitiveness of Chinese industry. The range of possibilities is numerous, but for simplicity and comparison across industries, the report assigns parameters of "low" or "high" for each dimension. This produces four major outcomes: 1) no concern; 2) negative impact; 3) positive impact; and 4) mixed impact. For each case study, current, short-term, and long-term effects are assessed. Timelines within industries differ, but in general short-term refers to the next 1–3 years, and long-term refers to the next 10+ years.

LOW IMPACT

In industries where there is low direct competition for US firms from Chinese firms and also low demand for US parts, technology, and IP, it can be expected that the resulting impact on US firms will be limited. These are the industries in which there is no strong US industrial base or expertise, and US firms are not among the leading actors, such as high speed rail. The overall impact on US industry, therefore, will be minor. On the consumption side, potential remains for positive and significant impacts which would result from Chinese firms marketing and selling their products to the United States, either directly, or indirectly as components in larger systems. An upgraded Chinese industry would likely lower costs of these products and services and would benefit US consumers.

NEGATIVE IMPACT

In industries where direct competition for US firms is high but demand for US parts, technology, and IP is low, the impact on US economic competitiveness from increased Chinese attention will likely be negative. As described earlier, increased direct competition for US firms may not only affect profitability and market share of firms in China, but may also have indirect implications for US production and workforce. In most cases, movement into this quadrant will occur over time as Chinese policies aimed at increasing the competitiveness of Chinese firms take effect and these firms begin to replace US firms as suppliers in the Chinese market.

In some cases, however, the low demand for US parts, technology, and IP will result from discriminatory policies that favor Chinese firms over foreign counterparts. Negative effects could also occur as Chinese firms invest abroad and compete with US firms in the United States, although it is believed that the negative effects from such cases will be small in comparison to negative effects in China.

POSITIVE IMPACT

Where direct competition for US firms is low but demand for US technology is high, the likely impact on US economic competitiveness will be positive. Less mature Chinese firms or even the lack of Chinese firms in an industry, however, does not always imply low direct competition for US firms. As described earlier, low competition for US firms would also need to include the absence or limited presence of market-distorting policies that favor Chinese firms over US firms. Many current industries currently experience this situation. The trend, however, is to move away from this quadrant, since the expectation is that Chinese firms over time will become more capable and stronger competitors. Positive impacts may also be found as Chinese firms invest in the United States. The trend of these investments is to support US supply chains and provide employment opportunities for local economies in the United States.

MIXED IMPACT

The last scenario involves both high direct competition for US firms and high demand for US technology. In these cases, the outcome is a combination of both positive and negative impacts on US economic competitiveness. Given the uncertainty and volatility of economic trends and drivers, it is virtually impossible to know whether the effects of increased Chinese competitiveness will be positive or negative for the United States in these cases. Although the overall impact on the United States is inconclusive, the analysis will focus on addressing the key factors to at least provide a sketch of the dynamics at play.

Industry Cases

The examination of China's state plans and plans for technological and industrial development and its implications for the United States has so far been largely focused at the national level, but it is also important to delve more deeply and consider what is happening at the industry level. In this section, eleven industry case studies have been conducted covering four domains that have received prominent attention in several of the most recent plans and programs, particularly the Made in China 2025 plan.

Case studies were chosen strategically in order to provide a cross-section of industry sectors. All of those selected can be considered emerging industries, but choices were made such that both mature industries (integrated circuits, biopharmaceuticals) and industries still in development (5G, additive manufacturing) are included. Additionally, the case studies include industries in which the United States and China are at varying positions of global leadership. The selected industries are:

1. **Information and communications technology (ICT):** 5G technology, cloud computing, global navigation satellite systems, and integrated circuits
2. **Manufacturing:** Additive manufacturing, advanced robotics, and nanomaterials
3. **Transportation:** Electric vehicles and high speed rail
4. **Medical and healthcare:** Biopharmaceuticals and medical devices

5G Technology

Successive generations of mobile technology have enabled upgrading of telecommunication service from call and text message to today's app-centric interface. Currently, 4G networks are the dominant contributor to mobile communication, but the challenge of providing low-power, low-frequency networks to meet the demand for widespread machine-to-machine services and the IoT has spurred many countries and companies to pursue the development of 5G technology.[519]

In the global race for 5G research, development, and deployment, the present front-runners are South Korea, Japan, the European Union, and the United States. While China technologically is not a contender as of yet, it is not too far behind. In any case, China can be expected to be a fast adopter of 5G technology and standards, and may even roll out nationwide networks ahead of the United States. If realized, these advancements will come not just from China's state-defined goals but also from its strong involvement in international standard setting and regulatory bodies and proactive investment in domestic 5G R&D and industry development. As 5G technology development is still at an early stage, however, trajectories could change prior to its expected commercial deployment by the end of this decade.

Market Characteristics

According to the EU's 5G development roadmap, the European 5G network will have wireless capacity 1,000 times higher than in 2010 once the technology is fully deployed. The network will have the ability to allow access to 7 trillion units of wireless devices to serve 7 billion people. Compared with the current 4G technology, 5G technology's peak rate will increase more than 10 times, from 100 megabytes per second (Mb/s) in 4G to more than 10 gigabyte/second (G/s).[520] These numbers are expected to be reflective of 5G wireless capacity globally.

Due to its rapidly growing mobile market and connected population, China is highly incentivized to invest in 5G technology. China's IMT (International Mobile Telecommunications)-2020 (5G) Promotion Group—established in 2013 by MIIT, NDRC, and MOST—forecasts that China's mobile data traffic growth will be higher than the global average, with expectations that growth will multiply more than 300 times from 2010 to 2020, and 40,000 times from 2020 to 2030. By comparison, global mobile data traffic is expected to grow 200 times from 2010 to 2020, and 20,000 times from 2020 to 2030. Mobile data traffic growth rates in developed and "hot" cities in China are projected to be even higher. For example, the growth rates in Shanghai and Beijing from 2010 to 2020 are projected at 600 times and 1,000 times, respectively. In addition, China is expected to account for one-fifth of the world's 10 billion mobile terminals (excluding devices connected to the IoT) by 2020.[521]

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[519] GSMA Intelligence, "Understanding 5G: Perspectives on Future Technological Advancements in Mobile," December 2014, https://gsmaintelligence.com/research/?file=141208-5g.pdf&download.

[520] Hou Yunlong and Zhang Xiaoru, "多国竞追 5G 战略制高点" [Multiple Countries Chasing 5G Strategic High Ground], 经济参考报 [*Economic Information Daily*], April 10, 2015, http://www.jjckb.cn/2015-04/10/content_544138.htm.

[521] "推进组-5G 愿景与需求白皮书 IMT-2020(5G)" [Advanced Group: 5G Vision and Demand White Paper (IMT-2020(5G))], May 2014, http://wenku.baidu.com/view/725a6c74a5e9856a561260bd.html.

Technology Levels

5G technology for the most part is still in the R&D stage, although it is quickly nearing testing and deployment. Countries are currently racing to be the first to commercially deploy the technology. Verizon Wireless recently announced an ambitious goal of deployment in the United States in 2017, although this will be limited to a few as-of-yet unannounced locations. South Korea is aiming to deploy in time for its 2018 Winter Olympics, and China's goal is to deploy by 2020.[522]

US companies had largely been absent from news headlines regarding progress in 5G technology, with the exception of select US companies participating in international fora and consortia. This led some analysts to believe that the United States lagged its foreign competitors in technology development, although others declare that the United States has done everything it can to advance 5G and has not isolated itself in any aspect of its development.[523] One major indication of US activity in 5G is Verizon's announcement in early September 2015 that it would begin 5G field tests in 2016 and is looking to begin limited commercial deployment in 2017, one year earlier than the previously expected first deployment by South Korea.[524] To achieve its plan, Verizon formed the Verizon 5G Technology Forum, which includes the leading technology companies Alcatel-Lucent, Cisco, Ericsson, Nokia, Qualcomm, and Intel.[525]

Chinese companies are investing significantly in 5G technology. Huawei CEO Hu Houkun stated said that the company will spend approximately 10 percent of its 2014 R&D expenditures (about $60 million) to develop 5G technology. By 2018, Huawei estimates it will have invested at least $600 million in 5G technology "research and innovation." Altogether, Huawei has already established nine global 5G R&D centers employing more than 300 engineers. China Mobile has also stated its support for development of 5G technology.[526]

ZTE has taken a slightly different route and is promoting what it calls "pre-5G." Introduced in July 2014, "pre-5G" incorporates aspects of 5G technology into existing 4G terminals without changing air interface standards.[527] ZTE and China Mobile have already completed their first test runs for "pre-5G." If commercially viable, this technology could provide speeds ten times faster than current 4G mobile Internet before full 5G deployment.[528]

As China pushes its domestic 5G technology, its firms are partnering with international companies. China Mobile, NTT DoCoMo, and KT Corporation (formerly Korea Telecom) announced at the

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522 Roger Cheng, "Verizon to be First to Field-Test Crazy-Fast 5G Wireless," *CNET*, September 8, 2015, http://www.cnet.com/news/verizon-to-hold-worlds-first-crazy-fast-5g-wireless-field-tests-next-year/.

523 See Linda K. Moore, "Deploying 5G (Fifth Generation) Wireless Technology: Is the United States on Track?" *CRS Insights*, October 21, 2014, https://www.fas.org/sgp/crs/misc/IN10110.pdf. The contrasting viewpoint comes from author interview with expert on telecommunications policy from US National Telecommunications and Information Administration, January 12, 2016, Washington, D.C.

524 Cheng, "Verizon to be First to Field-Test Crazy-Fast 5G Wireless."

525 "Verizon Sets Roadmap to 5G Technology in US; Field Trials to Start in 2016," news release, September 8, 2015, http://www.verizon.com/about/news/verizon-sets-roadmap-5g-technology-us-field-trials-start-2016.

526 Advanced Group: 5G Vision and Demand White Paper.

527 Ibid.

528 George Chen, "China to Get '10 Times Faster' Pre-5G Internet in 2016 Amid Premier's Push for Tech Development," *South China Morning Post*, July 16, 2015, http://www.scmp.com/tech/innovation/article/1840079/china-get-10-times-faster-pre-5g-internet-2016-amid-premiers-push.

2015 World Mobile Communications Conference that they will work together to meet the Asian market's 5G demands.[529] In March 2014, Huawei signed an agreement with NTT DoCoMo, Japan's largest mobile service provider, to carry out a 5G joint test, and in November 2014, Huawei joined the 5G Innovation Center at the University of Surrey, announcing the launch of the world's first 5G communication technology test bed.[530] According the University of Surrey, "[t]he testbed will be progressively upgraded as 5G technology begins to emerge, to allow the next wave of applications and services to be explored."[531]

Much of this work by Chinese companies is in tandem with efforts made by European companies. In November 2012, the European Union launched the €27 million ($29.5 million) METIS project (Mobile and wireless communications Enablers for the Twenty-twenty Information Society) to lay a foundation for 5G technology. The 29 partners included equipment manufacturers (including Huawei), operators, and academic institutions. Additionally, the European Commission (the executive body of the EU) launched a public-private partnership in December 2013 that will allocate €7 billion ($7.65 billion) over the next seven years to support 5G technology R&D.[532] In the United Kingdom, the €80 million ($87.5 million) 5G Innovation Center built at the University of Surrey will be used as a test bed for trials of emerging 5G ideas, technology, and validating standards.[533]

Policy Measures

MIIT, NDRC, and MOST are pushing forward public and private engagement in 5G R&D. In February 2013, they established the IMT-2020 (5G) Promotion Group, whose objectives include "developing 5G technologies for China and facilitating cooperation with foreign companies."[534] Main contributors to the group include China Mobile, MIIT's China Academy of Telecommunication Research, Huawei, Datang Telecom Technology and Industry Group, China Telecom, ZTE, and China Unicom.[535] Highlighting China's emphasis on this new sector, 5G was listed as the first "core key" technology for a major breakthrough—a designation implying concerted government effort to coordinate scientific and technological resources—at the annual National Science and Technology Work Conference held in early 2014.[536]

The 863 Plan is a financier and promoter of 5G technology development in China. In November 2014, it was reported that more than RMB 300 million ($46.6 million) had been invested in the technology through the 863 Plan's "Fifth-Generation Mobile Communication System Major R&D

[529] Advanced Group: 5G Vision and Demand White Paper.
[530] Ibid.
[531] Amy Sutton, "University of Surrey Announces Vision for 5G Alongside Major Industry Partners," University of Surrey, November 4, 2014, http://www.surrey.ac.uk/mediacentre/press/2015/university-surrey-announces-vision-5g-alongside-major-industry-partners.
[532] Ibid.
[533] 5G Innovation Center, University of Surrey, "About Us," https://www.surrey.ac.uk/5gic/about.
[534] Moore, "Deploying 5G (Fifth Generation) Wireless Technology."
[535] IMT-2020 (5G) Promotion Group, "White Paper: 5G Vision and Requirements," May 2015.
[536] Xiaofeng Guo, "华为推动 5G 全球统一标准 预计 2020 年商用" [Huawei Advances 5G Global Unified Standard, Estimates 2020 Commercialization], 腾讯科技 [Tencent Technology], November 19, 2014, http://tech.qq.com/a/20141119/051526.htm.

Project."[537] Recipient and participating organizations in this plan include leading academic institutions and companies, such as Tsinghua University, Beijing Jiaotong University, the University of Electronics Science and Technology, MIIT's Telecommunications Research Institute, State Radio Monitoring Center, China Electronics Technology Group, Huawei, ZTE, and more than 50 other organizations.[538] Other 863 Plan projects, such as the "Fifth-Generation Mobile Communications System Preliminary R&D" project, are also investing significant funds in 5G technology development. Phase I of this project is shown in Table 8.

5G technology is receiving additional support through the recent Internet Plus plan, which is driving companies to invest heavily in future mobile communications technology. While not specifically focused on mobile technology, Internet Plus aims to upgrade the connectivity of many traditional industries to enhance competitiveness. Other non-traditional sectors, such as auto networking (driverless cars) and Industrial Internets (the industrial application of the IoT), will require enhanced data transmission speeds and broadband capabilities that are expected to be created by 5G deployment.[539]

Since the announcement of Internet Plus, many companies have sought to link their 5G initiatives to the broader government plan. Huawei executives are using similar language to that contained in the Internet Plus plan to explain their development activities. They talk about integrating the wireless Internet with traditional economic sectors such as banking and agriculture "to make them more information driven, to make them more intelligent."[540] ZTE and China Mobile's joint effort to push "pre-5G" won government support partly because of its consistency with the Internet Plus strategy to push for faster integration of traditional sectors and new digital services.[541] According to China Mobile Executive Vice President Li Zhengmao, "China Mobile has always been a strong promoter of mobile broadband technology and will continuously boost the development of Internet Plus by providing premium network and technology support."[542]

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537 "工信部已投 3 亿启动 863 计划 5G 研发项目" [MIIT Invested RMB 300 Million to Launch 863 Plan's 5G R&D Project], 沙发论坛 [Sofa Forum], November 19, 2014, http://bbs.shafa.com/article-233-1.html.

538 "5G 研究升温意味着什么" [What Does the Thawing of 5G Research Mean?], Panda Electronics Group Co., Ltd., accessed January 25, 2016, http://www.panda.cn/SJTCMS/html/PandaJT/pandajt201311/93284263.asp.

539 Zhong Lingjiang, "奚国华: "互联网+"将成 5G 发展加速器" [Xi Guohua: 'Internet+' to Become Accelerator of 5G Development], 人民邮电报 [People's Posts and Telecommunications News], July 16, 2015, http://www.cnii.com.cn/telecom/2015-07/16/content_1599688.htm.

540 Charles Clover, "Huawei Boosts R&D Spending as 4G Revolution Marches On," *Financial Times*, March 31, 2015, http://www.ft.com/cms/s/0/cfe56200-d761-11e4-94b1-00144feab7de.html#axzz3jkug95Pq.

541 Chen, "China to Get '10 Times Faster' Pre-5G Internet."

542 Li Zhengmao, "China Mobile: Mobile Broadband Boosts the 'Internet Plus'," GTI Summit 2015 Shanghai, July 28, 2015, http://www.gtigroup.org/gti2015sh/KeynoteSpeech/2015-07-28/6832.html.

Table 8. 863 Plan "Fifth-Generation Mobile Communications (5G) System Preliminary R&D (Phase I)"

In preparation for 2020 implementation of 5G mobile communications:

1. Wireless network architecture and key technology R&D

Budgetary allocation: RMB 50 million ($7.75 million), implemented over 3 years

- System data for business support to reach capacity of 10 Gbps
- Spectrum and power efficiency to reach 10 times level of 4G
- Network coverage per unit area to reach 25 times level of 4G

2. 5G wireless transmission key technology R&D

Budgetary allocation: RMB 60 million ($9.33 million), implemented over 3 years

- Perform testing of wireless transmission technology
- Number of cooperative base station antennas to exceed 128
- Spectrum and power efficiency to reach 10 times level of 4G

3. 5G mobile communication system overall technology research

Budgetary allocation: RMB 20 million ($3.11 million), implemented over 3 years

- Research 5G business applications and needs, business development models, user experience models, network development strategy, spectrum requirements, and air interface technology demand
- Submit report of research on overall technology evolution and development

4. 5G mobile communication technology evaluation and test verification technology research

Budgetary allocation: RMB 30 million ($4.67 million), implemented over 3 years

- Research methods for testing and evaluating 5G mobile communication networks and wireless transmission technology
- Establish platforms for 5G mobile communication network simulation testing and evaluation and transmission technology simulation testing and evaluation.
- Complete 5G mobile communication network and wireless transmission technology testing and evaluation.
- Submit report of results.

Source: Ministry of Science and Technology, "国家 863 计划"第五代移动通信系统研究开发"重大项目（一期）" [National 863 Plan "Fifth-Generation Mobile Communication System Research and Development" Major Project], June 5, 2013, http://www.bit.edu.cn/docs/20130605093208446905.doc.

Implications for the United States

China wants to be a leader in setting 5G technology standards, building on its past successes. China developed TD-SCDMA as one of the three 3G international standards and TD-LTE as one of the two 4G international standards. By June 2015, TD-LTE had been used in 37 countries and areas by 63 commercial networks. Base stations supporting TD-LTE technology currently account for half of global 4G base stations, providing mobile networks to 33.76 percent of global 4G users with more than 1,000 models of terminals.[543] China hopes to command similar or larger market shares in 5G technology.

If China leads in 5G technology, US telecommunication companies could lose significant amounts of royalty income on patents. Chinese telecommunication companies have been able to negotiate waivers of royalty payments to US semiconductor firm Qualcomm for TD-SCDMA and TD-LTE networks. However, they are still paying high licensing fees to Qualcomm when using the CDMA,

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543 Xie Lirong, "中国将如何角逐 5G 标准?" [How Will China Compete for 5G Standards?], Baidu Baijia, September 9, 2015, http://xielirong.baijia.baidu.com/article/161598.

WCDMA (3G), and FDD-LTE (4G) standards. China and Europe have been cooperating on developing a 5G standard based on cellular networks, instead of US 5G standards based on Wi-Fi technology.[544] As a gauge of the magnitude of potential revenue losses to US firms, Qualcomm's revenue in China in 2013 increased to $12.3 billion, accounting for 49 percent of its global revenue.[545] Globally, Qualcomm's royalties accounted for 29 percent of its profit and 77 percent of its revenue.[546] It should be noted, however, that there is an immense push to have a global standard for 5G. While the Chinese government is very active in the standard setting process, it may have limited ability to favor local Chinese standards over those belonging to US or other foreign firms. China's increased activity within ITU should also not be seen as threatening to local US standards. China, Korea, and Japan are all pushing to wield more influence within the ITU, but whether they will be successful is far from clear.[547]

China's state-promoted telecommunications industry, however, could still have negative implications for US economic competitiveness. Over the long term, US chip manufacturers are a vulnerable industry group and could take a severe hit to their global business. A China-influenced 5G standard could be expected to accelerate the development of the Chinese chip industry. A unified 5G international standard would decrease R&D costs to chip companies as they pursue technological breakthroughs.[548] Currently, more than 97 percent of chips used in Chinese-made mobile phones are imported. With the development of a homegrown chip industry in China, US chip suppliers will face a significant loss of market share. This loss was seen in the development of 3G TD-SCDMA technology, which provided support to the development of Chinese manufacturers of TD-SCDMA chips. Several Chinese domestic chip companies, including Leadcore Technology and Spreadtrum Communications, were established at that time.[549] Chinese companies are now seeking to increase their share in the 4G market. For example, Chinese chipmaker Spreadtrum Communications, one of the leading Chinese competitors, announced plans at the beginning of 2016 to invest over RMB 300 billion ($US 46.4 billion) over the next five years.[550] Established player Huawei has gained prominent attention for its support of "Made in China" chips with its home-made processor Kirin 950, with which it hopes to directly challenge Qualcomm and Taiwan-based MediaTek.[551]

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544 "中国通信制造业需要 5G 标准" [The Chinese Telecommunication Industry Needs the 5G Standard], Sina, November 7, 2014, http://tech.sina.com.cn/zl/post/detail/t/2014-11-07/pid_8464421.htm.
545 "高通反垄断结果或将公布可能面临 12 亿美元罚金" [Results of the Qualcomm Anti-Monopoly Case May Be Announced: Qualcomm May Be Fined $1.2 Billion] 新浪科技 [Sina Technology], December 4, 2014, http://tech.sina.com.cn/it/2014-12-04/doc-icczmvun0923660.shtml.
546 Gordon Chang, "Qualcomm in Quicksand, Its China Problem Not Fixable," *Forbes*, July 27, 2014, http://www.forbes.com/sites/gordonchang/2014/07/27/qualcomm-in-quicksand-its-china-problem-not-fixable/#6d63983849e2.
547 Author interview with expert on telecommunications policy from US National Telecommunications and Information Administration, January 12, 2016, Washington, D.C.
548 Xie Lirong, "How Will China Compete for 5G Standards?"
549 "The Chinese Telecommunication Industry Needs the 5G Standard."
550 "China's Tech Companies Eye Becoming Chip Manufacturers," *China Daily*, January 4, 2016, http://www.china.org.cn/business/2016-01/04/content_37447980.htm.
551 Tom McGregor, "Charging Ahead on 'Made-in-China' Chip Technology," CNTV, January 5, 2016, http://english.cntv.cn/2016/01/05/ARTI1451983973090134.shtml.

There is not a significant first-mover advantage in the 5G industry with the exception of increased marketing benefits. However, early Chinese deployment of 5G technology would also give a strong advantage to Chinese companies and industries in key sectors outside of mobile technology. For example, 5G technology is expected to be the backbone of companies in China and the United States that are investing heavily in the IoT. Successful rollout will be highly dependent on the availability of the spectrum and bandwidth that will come with 5G technology. This affects industries such as mobile healthcare, intelligent transportation, intelligent manufacturing, smart homes, industrial controls, remote construction/maintenance, and environmental monitoring.[552] 5G technology will significantly raise the capabilities of mobile cloud storage.[553] China's focus and leadership in 5G technology will also give a good-sized boost to its IC design and manufacturing industries.[554]

Conversely, China's development of its 5G network could strongly benefit US companies investing and doing business in China. Studies show that higher levels of ICT investment lead to increasing FDI inflows as it facilitates international communications between parent companies and their overseas affiliates and lowers transaction and production costs for foreign investors.[555] 5G-enabled countries also will attract capital investments and FDI as companies factor the availability of quick connectivity into their cost structures.

It seems clear that as China develops its 5G industry, there will be increasingly more negative implications for US economic competitiveness. While China's becoming a leader is still dependent on many factors, it is already investing heavily in its goal to become a front-runner. Currently, as 5G technology is still in development stage, there are few implications for US firms, workforce, or production. In the broad telecommunications industry that encompasses 5G, there is still a significant demand for US parts, components, and IP, and a moderate level of direct competition for US firms.

As China develops its 5G industry, however, it aims to indigenize its technology and supply chain, which will result in negative implications for US firms (see Figure 15). Much of this is likely to be fed by the close connection between national security and the telecommunications industry and the perceived need to ensure telecommunications is "secure and controllable."

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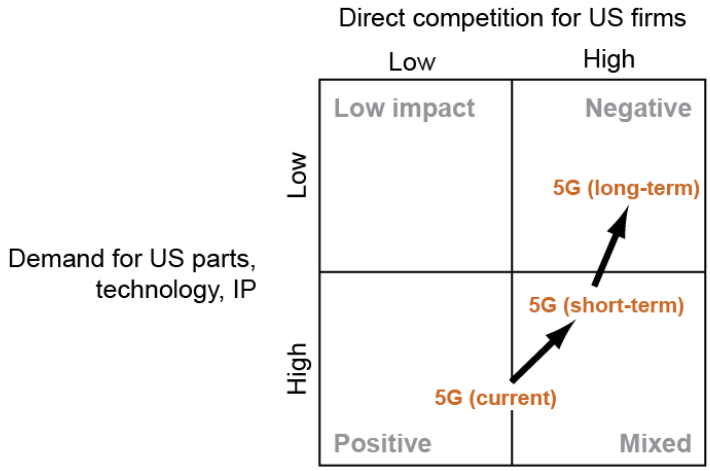
552 "各国巨头抢滩 5G 我国领跑 5G 不再是梦" [Global Leaders Competing for 5G, China Leading 5G Is No Longer a Dream], 中国科技网 [*Science and Technology Daily*], August 10, 2015, http://www.wokeji.com/shouye/mts/201508/t20150810_1539509.shtml.

553 Antony Adshead, "Egnyte: 5G the Tipping Point for Cloud Storage," *Computer Weekly*, March 14, 2013, http://www.computerweekly.com/blogs/StorageBuzz/2013/03/egnyte-5g-the-tipping-point-fo.html.

554 "抢先布局 5G 带动仪器仪表产业升级" [Racing to Roll Out 5G Drives the Upgrade of the Measuring Instrument Industry], Zhinenghua website, May 15, 2015, http://www.zgznh.com/news/show-838496.html.

555 Roghieh Gholami, Sang-Yong Tom Lee, and Almas Heshmati, "The Causal Relationship Between Information and Communication Technology and Foreign Direct Investment," *World Economy* 29, No. 1 (2006): 43–62, http://www.econstor.eu/bitstream/10419/52991/1/369108353.pdf.

Figure 15. Outcomes of Chinese investment in 5G technology for US firms



Cloud Computing

"Cloud computing," according to the US National Institute of Standards and Technology (NIST), is "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction."[556] This cloud model is composed of four deployment models: private, community, public, and hybrid.

The four models differ in terms of infrastructure, level of security, and how much management is required.

- Private clouds are either managed directly by an organization or by a third party on their behalf and may be physically located on or off the premises.[557] Private clouds are preferred by organizations that deal with sensitive data, such as state-owned enterprises, financial institutions, and government entities.
- Community clouds fall between public and private clouds, and may be "owned, managed, and operated by one or more organizations in the community, or a third party."[558] Health Leads, for example, uses the community cloud service from Salesforce to connect 20 health centers across the United States.[559]
- Public cloud infrastructure is available to the general public or large industry groups. It is owned by a cloud service provider and offers access to any user with an Internet connection. The service is used by organizations from large tech companies to SMEs, offering low-cost

[556] Peter Mell and Timothy Grance, "The NIST Definition of Cloud Computing: Recommendations of the National Institute of Standards and Technology," September 2011, 2, http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf.
[557] Sumit Goyal, "Public Versus Private Versus Hybrid Versus Community–Cloud Computing: A Critical Review," *International Journal of Computer Network and Information Security* 3 (2014): 20–29. doi: 10.5815/ijcnis.2014.03.03.
[558] Ibid.
[559] "Health Leads," Salesforce.com, accessed January 29, 2016, http://www.salesforce.com/customers/stories/health-leads.jsp.

features and the ability to scale to meet elastic demand. However, there are drawbacks with data security, reliability, and privacy.[560]

- A hybrid cloud is more complex than the other deployment models, with an infrastructure composed of two or more clouds. Organizations using a hybrid model could, for example, store their customer relationship management data in a public cloud but hide their confidential data in a private cloud.[561]

China and the United States are currently at different stages of cloud computing development. China is in the process of setting up cloud infrastructure and transitioning to cloud technologies. The United States is already a global leader and much further along the development path. However, with strong government support and abundant funding to develop cloud technologies, China has the potential to quickly catch up with the United States and challenge its monopolistic position.

Market Characteristics

The cloud computing industry has experienced rapid development since its establishment in 2005 in the United States. The global cloud computing market reached $137.1 billion in 2013 and is expected to reach $244.2 billion in 2017 with a 15 percent annual growth rate. The total US market size reached $30 billion in 2013. In contrast, the overall Chinese cloud computing industry scale was only around $2.7 billion in 2013.[562] While China is at an earlier stage in cloud adoption than other large economies, it is clear that the market is expanding noticeably and poised for significant future growth. The Chinese cloud computing market is projected to reach $6.9 billion in 2017 with a compound annual growth rate (CAGR) of 27.8 percent, according to International Data Corporation (IDC) estimates.[563]

The Chinese cloud computing industry consists of three markets: private cloud, public cloud, and cloud service providers. Both private and public clouds account for a sizeable market share. The private cloud market is estimated to reach $2.73 billion in 2017, up from $1.09 billion in 2013, and the public cloud market is projected to increase to $2.65 billion in 2017, up from $0.98 billion in 2013. The cloud service provider market is estimated to more than double, from $0.67 billion in 2013 to $1.48 billion in 2017.[564]

Due to the regulatory environment and the priorities of the Chinese IT sector, the majority of sales of corporate cloud computing services involves the deployment of private clouds.[565] However, the public cloud is also experiencing rapid growth. The CAGR for the Chinese public cloud from 2012

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[560] Goyal, "Public Versus Private Versus Hybrid Versus Community."
[561] Ibid.
[562] "2014 年中国云计算产业链剖析及市场规范测算" [2014 China Cloud Computing Industry Analysis and Market Estimation], 中国产业信息网 [chyxx.com], November 14, 2014, http://www.chyxx.com/industry/201411/293295.html; and Chen Jian, Li Wei and Wang Haobing, "云计算行业专题研究报告:掘金云服务" [Cloud Computing Industry Research Reports], CITIC Securities, September 2, 2014.
[563] Chen Jian, Li Wei and Wang Haobing, "Cloud Computing Industry Research Reports."
[564] Ibid.
[565] Leigh Ann Ragland, Joseph McReynolds, Matthew Southerland, and James Mulvenon, "Red Cloud Rising: Cloud Computing in China," research report prepared for the US-China Economic and Security Review Commission, September 5, 2013.

to 2017 is estimated to be 32 percent; by comparison, the global rate is estimated to be 22 percent.[566]

Public clouds provide service to customers through three service models: infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). IaaS offers provision processing, storage, networks, and other fundamental computing resources; PaaS provides development language, tools, and cloud infrastructure so that developers can publish applications; SaaS lets consumers use providers' applications running in the cloud.[567] PaaS is a more complicated model and requires a higher level of technology than IaaS, while SaaS replies on the development of IaaS and PaaS. Among the three public cloud service models within China's market, IaaS takes the largest share at around 66 percent in 2013. PaaS and SaaS accounted for 9 percent and 25 percent, respectively, of the total public cloud market in 2013. This structure, while consistent with China's lagged development stage of cloud computing, is different from the United States and other developed countries, where SaaS plays a dominant role. Chinese cloud service providers are mainly committed to provide infrastructure resources to major enterprises through IaaS.[568]

Developed countries have a dominant position in the global cloud computing market, especially the United States and Western Europe, whose combined global market share exceeds 75 percent.[569] A majority of global leading companies are US-based, such as Amazon, Google, Microsoft, Salesforce, VMware, and IBM. Amazon holds 40 percent of the global IaaS market, Microsoft holds 60 percent of the global PaaS market, and Salesforce holds 21 percent of the global SaaS market.[570]

Technology Levels

China is still in the process of setting up cloud infrastructure and transitioning to cloud technologies.[571] According to one US expert, the Chinese cloud computing industry lags technologically behind the world in general and Amazon's advanced cloud infrastructure in particular.[572] However, thanks to heavy government expenditure and support, cloud computing technology is growing significantly in China. A number of Chinese companies are competing with leading US companies in the Chinese cloud computing market, especially in the IaaS sector. China Mobile, China Telecom, and China Unicom, the three largest state-owned telecom companies, have undertaken various projects for development of cloud computing technologies in the country. Baidu and Ali Cloud, two of China's largest IT companies, are also investing in cloud computing in China. The former focuses on providing cloud storage infrastructure and technology services, while the latter focuses on providing cloud computing apps for the users.[573] Specialized IDC/IaaS providers are also very

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566 Chen Jian, Li Wei and Wang Haobing, "Cloud Computing Industry Research Reports."

567 Mell and Grance, "The NIST Definition of Cloud Computing."

568 Ibid.

569 China Academy of Telecommunication Research, "云计算白皮书 (2014)" [Cloud Computing Whitepaper 2014], May 2014.

570 Ibid.

571 Red Akrim, "The Growth of Cloud Computing in Emerging Asian Market," Cloudswave, February 18, 2015, https://www.cloudswave.com/blog/the-growth-of-cloud-computing-in-emerging-asian-market/.

572 Robert O'Brien, "Cloud Computing in China: An Insider's Perspective on the Chinese Attempt to Catch Up to Amazon," contextChina, May 1, 2013, http://contextchina.com/2013/05/cloud-computing-in-china-an-insiders-perspective-on-the-chinese-attempt-to-catch-up-to-amazon/.

573 Akrim, "The Growth of Cloud Computing."

active in the market.[574] On the other hand, because of technology barriers and limited market size, only Internet giants such as Alibaba and Baidu are present in the PaaS and SaaS market, competing with Amazon, Microsoft and Salesforce.[575]

Some analysts believe that China will quickly catch up with the global leaders because of the current pace of development of cloud technology in China.[576] Zhao Yi, an associate researcher at the Institute of Computing Technology at the CAS, has said that the development of Chinese cloud computing technology has allowed it "to break what it felt [were] monopolistic positions held by Europe and the United States."[577]

Policy Measures

The Chinese government has guided the direction of cloud computing development through strategic investment and support. In 2010, cloud computing was identified as part of one of the SEIs.[578] Development of cloud computing was then declared a top priority in the government's 12th FYP.[579] A series of policies were subsequently launched, including the 12th Five-Year Special Plan for Cloud Computing Technology (中国云科技发展"十二五"专项规划) issued by MOST, and the 12th Five-Year Plan for the Software and Information Technology Service Industry (软件和信息技术服务业"十二五"发展规划) and 12th Five-Year Plan for the Internet Industry (互联网行业"十二五"发展规划), both issued by MIIT.[580] These plans will facilitate core cloud computing technology research, establishment of Chinese cloud computing standards, development of cloud computing integrated systems, and enhancement of cloud security. More recently, in 2015 the State Council issued the "Opinions on Promoting Innovative Development of Cloud Computing and Fostering the New Form of Information Industry（国务院关于促进云计算创新发展培育信息产业新业态的意见）. The guidance states that "by 2020, China's cloud computing services capacity

[574] Chen Jian, Li Wei and Wang Haobing, "Cloud Computing Industry Research Reports."
[575] Ibid.
[576] Akrim, "The Growth of Cloud Computing."
[577] E. L. Borromeo, "With Government's Efforts in Cloud Computing, China May Surpass Developed Countries," yibada.com, August 20, 2015, http://en.yibada.com/articles/56042/20150822/government-s-efforts-cloud-computing-china-surpass-developed-countries.htm.
[578] "国务院关于加快培育和发展战略性新兴产业的决定" [The State Council's Decision to Accelerate Fostering and Developing Strategic Emerging Industries], PRC Central Government website, October 18, 2010, http://www.gov.cn/zwgk/2010-10/18/content_1724848.htm.
[579] "国民经济和社会发展第十二个五年规划纲要(全文)" [The 12th Five-Year Plan for National Economic and Social Development (Full Text)], PRC Central Government website, March 16, 2011, http://www.gov.cn/2011lh/content_1825838.htm.
[580] Ministry of Science and Technology, "科技部关于印发中国云科技发展'十二五'专项规划的通知" [Ministry of Science and Technology's Notice to Issue 12th Five-Year China Cloud Computing Technology Special Plan], September 18, 2012, http://www.most.gov.cn/tztg/201209/t20120918_96838.htm; Ministry of Industry and Information Technology, "'互联网行业'十二五'发展规划》发布" ['Internet Industry' 12th Five-Year Development Plan Released], May 4, 2012, http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/14578923.html.

will reach international advanced levels, master key cloud computing technology, establish a comprehensive cloud computing information regulatory system, and have a number of leading enterprises that are competitive internationally."[581]

In July 2015, the State Council unveiled the Internet Plus Action Plan, which emphasizes cloud computing. The plan promotes cloud computing applications in nine broad economic sectors: collaborative manufacturing, intelligent energy resources, inclusive finance, consumer services, high-efficiency logistics, e-commerce, transportation, and green ecosystems. It is also intended to increase the international presence of Chinese Internet companies.[582]

The Chinese government's support for the development of the cloud computing industry is not limited to state-directed plans. In 2011, NDRC, MOF, and MIIT approved a special fund of RMB 1.5 billion ($233.25 million) to support cloud computing applications. Initial funding was appropriated to 15 demonstration projects within the five cloud trial cities: Beijing, Shanghai, Shenzhen, Hangzhou, and Wuxi.[583] In 2014, NDRC, MOF, MIIT, and MOST jointly launched the 2014 Cloud Computing Plan (云计算工程) to promote the construction of cloud computing platforms, big data services based on cloud computing, and solutions for cloud computing and big data.[584] Several enterprises have reported receiving sizable funding from this plan. For example, China TravelSky Holding Company and Industrial Bank received RMB 20 million ($3.11 million) from this plan to build public cloud computing platforms for civil aviation information services.[585] Industrial Bank Company, Ltd. (兴业银行) received 220 million ($34.21 million) to support its construction of a financial cloud computing platform to provide services to banks and financial institutions.[586]

The government has tried to further spur cloud computing by adding cloud computing services to the government procurement catalogue and launching an e-government initiative. A recent research report from Guotai Junan Securities estimated that Chinese government procurement of cloud services from 2014 to 2016 will grow 16 times, increasing from RMB 400 million ($62.2 million) to RMB 6.3 billion ($979.7 million), indicating that the government procurement of cloud services will soon become a major force behind cloud computing development.[587]

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581 "国务院关于促进云计算创新发展培育信息产业新业态的意见" [The State Council's Opinion on Facilitating the Innovative Development of Cloud Computing and Fostering the Information Industry], PRC Central Government website, January 30, 2015, http://www.gov.cn/zhengce/content/2015-01/30/content_9440.htm.

582 "国务院关于积极推进"互联网+"行动的指导意见" [The State Council's Guidance on Promoting the "Internet Plus" Action], PRC Central Government website, July 4, 2015, http://www.gov.cn/zhengce/content/2015-07/04/content_10002.htm.

583 "云计算十三五规划启动" [Launch the 13th Five-Year Plan for Cloud Computing], 中国云计算 [*China Cloud*], August 11, 2014, http://www.chinacloud.cn/show.aspx?id=17429&cid=18.

584 National Development and Reform Commission, "关于印发云计算工程实施方案的通知" [Notice on Issuing Action Plan of Cloud Computing Project], December 31, 2014, http://www.sdpc.gov.cn/zcfb/zcfbtz/201504/t20150416_688290.html.

585 "中航信获国家 2014 年云计算工程专项资金支持" [TravelSky Technology Received Special Funds from the 2014 Cloud Computing Project], 网易新闻 [*NetEase News*], September 15, 2014, http://news.163.com/air/14/0915/09/A661T72S00014PHJ.html.

586 "兴业银行获 2014 年云计算工程专项资金支持项目约 2.2 亿" [Industrial Bank Company Received RMB 220 Million Special Fund from the 2014 Cloud Computing Project], *People's Daily*, August 4, 2014, http://finance.people.com.cn/bank/n/2014/0804/c202331-25397961.html.

587 "Launch the 13th Five-Year Plan for Cloud Computing."

A number of cloud computing research projects have been included in the 863 and 973 plans. Table 9 shows projects initiated in 2014 and 2015 that are related to cloud computing technology.

Table 9. 863 and 973 plan projects on cloud computing technology

Year	Project Name (English)	Project Name (Chinese)	Duration
863 Plan			
2015	Scale testing and verification of Software Defined Network (SDN) for multi-service convergence	面向多业务融合的软件定义网络（SDN）规模试验与验证	2 years
2015	Key technology and platform of cloud computing application service development environment	云计算应用服务开发环境关键技术及平台	3 years
2015	Key technology and system of hybrid cloud for Chinese cloud products	基于中国云产品的混合云关键技术与系统	3 years
2015	Adaptive collaboration and scheduling platform for cloud and terminal	云端和终端资源自适应协同与调度平台	3 years
2015	Third-party cloud platform trust rating evaluation technology	面向第三方的云平台可信评测技术	3 years
2015	Detection technology of malicious activity in cloud computing environment	云计算环境中恶意行为检测技术	3 years
2015	Cloud security responsibility and control technology based on information flow	基于信息流的云安全追责、管控技术	3 years
2015	Privacy protection technology of cloud data	云数据隐私保护技术	3 years
2015	Reliable cloud security service and demonstration application	云安全的可信服务及其示范应用	3 years
973 Plan			
2014	Cyberspace big data computing theory	网络信息空间大数据计算理论	5 years
2014	Research on the basic theory of computing of network large data and its application	网络大数据计算的基础理论及其应用研究	5 years
2014	Research on the theory and method of cloud computing security	云计算安全基础理论与方法研究	5 years
2014	Large scale heterogeneous data analysis, mining and management	大规模异质数据分析、挖掘与管理	5 years
2014	Basic theory and key technology of software defined cloud data center network	软件定义的云数据中心网络基础理论与关键技术	5 years
2015	The theory and method of three dimension large data computing in urban management	面向城市管理的三元空间大数据计算理论与方法	5 years
2015	The theory and method of three dimension spatial cooperative computation for urban big data	城市大数据三元空间协同计算理论与方法	5 years
2015	Calculation theory and method of city big data	城市大数据的计算理论和方法	5 years
2015	Basic theory and key technology of large data group computation	大数据群体计算的基础理论与关键技术	

Sources: Ministry of Science and Technology, "国家高技术研究发展计划（863 计划） 2015 年度项目申报指南" [2015 National High-Tech Research and Development Plan (863 Plan) Application Guide], http://www.most.gov.cn/tztg/201402/W020140221598529377115.doc; "2014 年国家重点基础研究发展计划(973 计划)项目专项经费预算拟安排情况汇总表" [2014 National Basic Research and Development Plan (973 Plan) Summary of Special Budget], Baidu.com, November 12, 2013, http://wenku.baidu.com/view/8d388ae95fbfc77da369b100.html; Ministry of Science and Technology, "关于国家重点基础研究发展计划（973 计划）2015 年新立项项目预算安排（前两年）初步方案的公示," [Announcement of 2015 Budgetary Arrangements for New National Basic Research and Development Plan Projects (First Two Years)], December 10, 2014, http://www.most.gov.cn/tztg/201412/t20141210_116929.htm.

Implications for the United States

The United States and Europe still have a leading position in the global cloud computing market. This structure, as the China Academy of Telecommunication Research has pointed out, will not change significantly in the next few years because of several constraints that affect the development of the cloud computing industry. These include national informationization and economic development levels, and overall development of the ICT industry.[588] The Chinese cloud computing industry also faces other hurdles, including the lack of a mature evaluation and certification mechanism or technical and operational standards, and concerns about data security.[589] However, US firms are expected to face growing competition with Chinese firms both in China and globally.

Domestically, the Chinese government will continue to promote the activities of local companies with support from various state plans, special funding, and government procurement. Globally, two major Chinese Internet companies, Alibaba and Tencent, took steps toward "going out" soon after the launch of the Internet Plus plan. Alibaba Group Holding announced in July 2014 that it would invest $1 billion into its Aliyun cloud computing arm to challenge Amazon's lucrative web services division. Aliyun President Simon Hu commented that "our goal is to overtake Amazon in four years, whether that is in consumers, technology, or worldwide scale."[590] Tencent also plans to invest RMB 10 billion ($1.55 billion) in its cloud computing business over the next five years in a bid to challenge Alibaba, Amazon, and Microsoft.[591]

Additional demand for US products and technology in China is uncertain. US firms face several challenges in seizing cloud-related opportunities in China. As in other industries, the regulatory environment is the first challenge.[592] Foreign investment is restricted in value-added telecommunications services, which means that US companies must enter into joint ventures with Chinese companies in order to provide cloud computing services to Chinese consumers from data centers in China. Leading US firms are actively pursuing partnerships and opportunities in China, but it is unclear whether or not US companies will benefit in the short or long term from these limited forms of market participation. Chinese regulations explicitly bar US corporations entirely from providing certain cloud services to select industries or types of institutions, such as the banking sector, which is a big consumer of cloud computing services.[593] On the other hand, regulations on cloud services in the US market are less restrictive for Chinese companies. For example, public

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[588] China Academy of Telecommunication Research, "云计算白皮书 (2014)" [Cloud Computing Whitepaper 2014], May 2014.

[589] "华经纵横: 浅谈云计算产业的发展现状及未来趋势" [Cloud Computing Industry Development Status and Future Trends], 中国产业竞争情报网 [www.chinacir.com.cn], June 27, 2014, http://www.chinacir.com.cn/2014_sdfx/419138.shtml.

[590] "Alibaba Cloud Unit Sets Sights on Amazon in $1 Billion Global Push," Reuters, November 11, 2014, http://www.reuters.com/article/2015/07/29/us-alibaba-cloud-idUSKCN0Q30TP20150729.

[591] Arjun Kharpal, "Tencent's $1.6b Plan to Take on Alibaba, Amazon in Cloud," CNBC, September 16, 2015, http://www.cnbc.com/2015/09/16/tencents-16b-plan-to-take-on-alibaba-amazon-in-cloud.html.

[592] International Trade Administration, US Department of Commerce, "2015 Top Markets Report: Cloud Computing: A Market Assessment Tool for US Exporters," July 2015, 25–27, http://trade.gov/topmarkets/pdf/Cloud_Computing_Top_Markets_Report.pdf.

[593] Renee Barry and Matthew Reisman, "Policy Challenges of Cross-Border Cloud Computing (May 2012)," *Journal of International Commerce and Economics* 4, No. 2 (November 2012), May 2012 web version at http://www.usitc.gov/publications/332/journals/journalvol_iv_2.pdf#page=4.

cloud services provided via the Internet are under the purview of telecommunications regulators in China, but they are not in the United States.[594] This situation has put US firms at a disadvantage.

Other challenges include a lack of trust in foreign technology and concerns over national security. China began developing a trust rating index for cloud vendors in 2014.[595] Only those with full security clearance can be involved in government projects. Foreign cloud vendors will be permitted to participate, but may be required to provide key operating data and source codes to the Chinese government for national security reasons. Moreover, in a move to address increasing IT security concerns, China is reportedly looking to replace foreign technology with local products by 2020, especially those deployed in banks, the military, state-owned companies, and government agencies.[596]

Whether US firms can thrive in China will depend on their ability to navigate these obstacles as well as the willingness of Chinese companies to entrust their data to the cloud.[597] Currently, several US firms, such as Amazon and Microsoft, have been able to push into the sizable Chinese market through joint partnerships with local companies. Microsoft executives have attributed the success of its Azure service to its unique partnership model, which may facilitate smoother relations with regulators than would otherwise be the case.[598] If US firms can figure out how to win the trust of the government and local companies, they could be in a position to transform the industry.

Despite these challenges, the Chinese government's support for cloud computing has some positive implications for foreign companies. With the support of state plans, China's overall broadband infrastructure, a foundation for successful provision of cloud computing services, will improve in the next few years. Several state-directed plans, including Internet Plus, the "Broadband China" Strategy and Implementation plan ("宽带中国" 战略实施方案), and the 2006–2020 National Informatization Development Strategy (2006–2020 年国家信息化发展战略) have set the improvement of the network infrastructure as their goal. In addition, around RMB 2 trillion ($311 billion) is expected to be used to construct a better broadband infrastructure.[599] The improvements will grant more customers access to broadband and increase Internet speed in China. This not only helps to clear one of the biggest hurdles for US cloud providers that want to make inroads in China but also further expands the market.[600] The expansion of US cloud provider's business in China will, in turn, help to grow employment in the United States.

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594 "Chinese Cloud Service Providers Expand Overseas as Foreign Counterparts Explore Policy Possibilities in China," International Data Corporation, August 10, 2015, https://www.idc.com/getdoc.jsp?containerId=prCN25831815.

595 Eileen Yu, "China to Develop Trust Rating Index for Cloud Vendors," zdnet, December 22, 2014, http://www.zdnet.com/article/china-explores-trust-rating-index-for-cloud-vendors/.

596 Ibid.

597 "Can Amazon and Microsoft Crack Cloud Computing in China?" *China Economic Review*, July 15, 2014, http://www.chinaeconomicreview.com/china-cloud-computing-microsoft-azure-amazon-aws-ibm-aliyun.

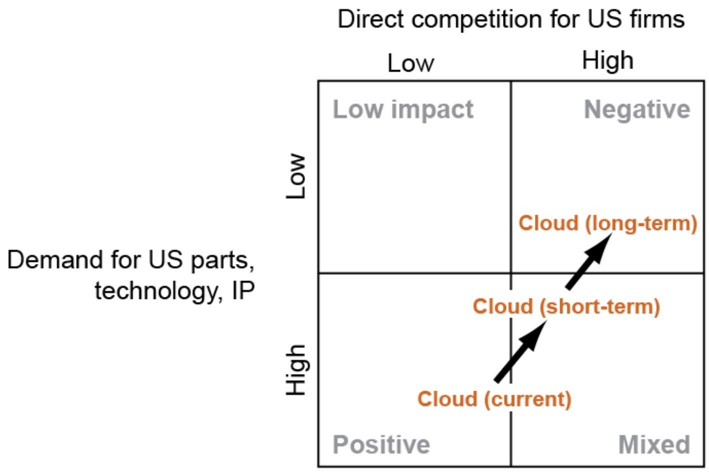
598 Ibid.

599 "互联网十三五规划将出 信息基础建设望撬动投资两万亿" [Internet 13th Five-Year Plan Is Coming, Information Infrastructure Construction Is Expected to Attract 2,000 Billion Investment], Xinhua Net, August 7, 2015, http://news.xinhuanet.com/fortune/2015-08/07/c_128103035.htm.

600 Kevin Meehan and Steven Lu, "Finding Opportunities in China's Cloud Market," *Forbes*, December 2, 2015, http://www.forbes.com/sites/baininsights/2015/12/02/finding-opportunities-in-chinas-cloud-market/#328442862692.

In summary, US firms are facing growing competition with Chinese firms and severe obstacles to Chinese market access. The Chinese government's plan to promote development of its domestic cloud computing industry and to be less dependent on foreign IT providers may have overall negative implications for US economic interests in the long term (Figure 16).

Figure 16. Outcomes of Chinese investment in cloud computing for US firms



Global Navigation Satellite Systems

A global navigation satellite system (GNSS) is a technology that enables users with a compatible device to determine their position, velocity, and local time by receiving and processing signals from satellites in space.[601] Satellite signals are provided by satellite positioning systems, including GPS (United States), GLONASS (Russia), Galileo (Europe), and Beidou (China).

National security is a primary concern in the GNSS industry and is a major driver for China to develop its own system. Outside of national security and military use, however, GNSS has wide commercial impact, and China is using state S&T plans and government policy to encourage domestic adoption of Beidou. So far, the impact on US companies is limited, but as Beidou improves in its precision and accuracy, it is expected that US companies and GPS will lose their dominant market position in China. Furthermore, as China completes its Beidou satellite constellation and plans to offer global coverage by 2020, the United States can expect increased competition in foreign markets.

Market Characteristics

Globally, there are 3.6 billion GNSS devices in use, dominated by 3.1 billion smartphone-based platforms to access location-based services (LBS) and followed by 26 million devices used for road applications in 2014.[602] Asia dominates the market with 1.7 billion devices in 2014 and is forecast to grow 11 percent per year to 4.2 billion in 2023.[603]

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[601] European Global Navigation Satellite Systems Agency, *GNSS Market Report* 4 (March 2015): 7, http://www.gsa.europa.eu/system/files/reports/GNSS-Market-Report-2015-issue4_0.pdf.
[602] Ibid., 8.
[603] Ibid.

Driven by the sales of smartphones, in-vehicle devices, location-aware applications, and data services, the core global market of GNSS was about $82.4 billion in 2014 with a forecast of 7 percent annual growth on average until 2023. LBS-related applications and road applications dominate the cumulative revenue with a combined total of more than 91 percent.[604]

In terms of GNSS downstream industry market share, as of 2012 the United States was the leader with 31 percent of the market, followed by Japan with 26 percent, Europe with 25.8 percent, and China at 7 percent.[605] The GNSS downstream industry can be broadly divided into three groups: 1) component manufacturers; 2) system integrators; and 3) value-added service providers. Based on 2012 revenues, Qualcomm (US), Trimble Navigation (US), and Broadcom (US) are the three leading component manufacturers; Toyota (Japan), Garmin (Switzerland), and General Motors (US) are the leading system integrators; and Google (US), Pioneer (Japan), and Denso (Japan) are the leading value-added service providers.[606]

According to the 2013 *Chinese Navigation Satellite and Service Industry Development White Book* (中国卫星导航与位置服务产业发展白皮书 (2013 年度)), the total revenue of Chinese navigation and positioning services was RMB 104 billion ($16.17 billion), 28.4 percent higher than 2012. GPS still dominates the Chinese market, with a market share over 90 percent. Beidou counts for close to RMB 10 billion ($1.55 billion), which is 9.8 percent of total revenues. Overall, the Chinese market is fragmented, with most Chinese companies either small or medium-sized enterprises.[607]

The Chinese market primarily consists of three categories: 1) the special (safety) application market covering military applications, public security, police, and emergency rescue; 2) the industry (field) application market that includes various fields of the economy, disaster prevention and mitigation, urban management, environmental management, and many other applications; and 3) the mass personal application market.[608]

The mass application market is currently concentrated on mobile phone location service and private vehicle applications. As the gradual improvement of the Beidou system and the terminal price gradually declines, the Beidou/GPS two-mode car navigator system is expected to become more mainstream. As the smartphone market also rapidly grew in 2013, annual sales reached 330 million units, and total output value of mass application and related location services reached more than RMB 20 billion ($3.11 billion).[609]

Within China, Chinese company NavInfo led the vehicle pre-mounted terminal market with a 60.2 percent market share in 2013, with second-ranked Chinese company AutoNavi with a 36.4 percent

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604 *GNSS Market Report*, 10.
605 Ibid., 11
606 Ibid.
607 "中国卫星导航与位置服务产业发展白皮书 (2013 年度)" [Chinese Navigation Satellite and Location Services Industry White Book (2013)], http://wenku.baidu.com/view/024966750722192e4536f6b4.html?re=view.
608 Ibid.
609 Ibid.

market share. NavInfo has led in market share since 2003.[610] However, in the Chinese mobile map navigation app market, AutoNavi leads the market with 32.6 percent share and Baidu Map ranks second with 24.9 percent.[611]

The Ministry of Communications had installed Beidou terminals in nearly 1.5 million vehicles across nine provinces and municipalities as of 2013. In the agricultural sector, the Ministry of Agriculture and the MOF's "2013 Subsidy Guide for the Purchase of Agricultural Machinery" (2013 年农业机械购置补贴实施指导意见) included "fishing boats with Beidou ship borne terminal" and "AIS [automatic identification system] ship borne" as types of equipment that can receive government subsidies. To date, 50,000 Beidou terminals have received this subsidy.[612]

Technology Levels

China now has twenty-two satellites in its Beidou navigation satellite system, with the twenty-second launched March 29, 2016. This has provided China with full coverage of China and neighboring regions, and it plans to expand Beidou services to most of the countries covered in its "One Belt, One Road" initiative by 2018 and to offer global coverage by 2020.[613] No further details on coverage area have been provided by China, but OBOR typically includes more than 60 countries from Singapore to Syria. Some significant advancements have come with China's implementation of Beidou. For example, it successfully developed high-level Beidou navigation chips and a Beidou mobile phone application with precision up to one meter.[614] The recently launched twentieth satellite also for the first time features a hydrogen maser atomic clock in place of the less-capable rubidium atomic clocks found in older satellites.[615] The newer clock will significantly increase the precision of the Beidou navigation signals.[616]

Based on global patent applications, US companies are ahead of Chinese companies in antenna, radio frequency, and baseband fields, with US companies accounting for 41.3 percent, 41.4 percent, and 38.7 percent, respectively. In other areas, however, such as positioning and GNSS smartphone applications, the largest number of applications comes from China, which account for

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610 "四维图新再次领跑车载前装导航市场 份额达到 60%" [NavInfo Leads Again in the Vehicle Pre-mounted Terminals; Market Share Reaches 60 Percent], 3sNews, March 14, 2014, http://www.chinaunsv.com/html/2014/news_0314/553.html.

611 "易观分析: 2013 年第 4 季度手机地图及导航商业模式发展走势趋同" [EnfoDesk Analysis: 4th Quarter 2013 Mobile Maps and Navigation Business Model Development Trends], EnfoDesk, April 3, 2014, http://www.enfodesk.com/SMinisite/newinfo/articledetail-id-404735.html.

612 Ibid.

613 "China Launches 20th Beidou Navigation Satellite," Xinhua, September 30, 2015, http://en.people.cn/n/2015/0930/c90000-8957409.html.

614 Wu Jingjing, "2014 年我国卫星导航与位置服务产业产值逾 1300 亿元" [The Output Value of China's Satellite Navigation and Location-based Service Industry Is More Than 130 Billion Yuan in 2014], 新华网 [Xinhuanet], September 10, 2015, http://news.xinhuanet.com/2015-09/10/c_1116526429.htm.

615 "China Launches 20th Beidou Navigation Satellite." Rubidium clocks lose only three seconds in one million years, while hydrogen maser clocks lose only one second in three million years. While seemingly small, the difference could produce a positioning error of meters. ESA, "How the Galileo Atomic Clocks Work," accessed February 22, 2016, http://www.esa.int/Our_Activities/Navigation/How_the_Galileo_atomic_clocks_work.

616 Kevin Pollpeter, "Upward and Onward: Technological Innovation and Organizational Change in China's Space Industry," in *China's Emergence as a Defense Technological Power,* ed. Tai Ming Cheung (London and New York: Routledge, 2013), 115.

39.5 percent and 35.6 percent, respectively. According to the State Intellectual Property Office, as of September 2013, China accounted for approximately one-third of total global patent applications in navigation satellite terminals.[617]

Policy Measures

Beidou and GNSS have received regular attention in state S&T plans in recent years (see Table 10). The initial focus was on implementing the launch and operation services systems needed to build and maintain a robust Beidou satellite constellation. In more recent plans, focus has shifted to building and expanding navigation application systems and consumer demand to gain greater market share. S&T plans that have touched upon Beidou include the MLP, the 12th FYP, the SEI plan, the 2013 State Council Opinions on Promoting the Information Consumption and Expanding Domestic Demand (关于促进信息消费扩大内需的若干意见), the Medium- and Long-term Development Plan for the National Navigation Satellite Industry (国家卫星导航产业中长期发展规划), and the Made in China 2025 plan.[618] In the SEI plan, short-term goals for 2015 and long-term goals to 2020 are outlined. By 2015, navigation positioning satellites should complete basic infrastructure implementation and have a complete application service system, satellite manufacturing and launching services, and a complete industrial chain for ground-based equipment manufacturing and satellite operation services. By 2020, China aims to achieve worldwide navigation positioning.[619]

The most significant plan for China's current satellite navigation industry is the State Council's 2013 Medium- and Long-term Development Plan for National Navigation Satellites, a national-level roadmap for the industry that signals that the satellite navigation application industry has become a major national strategy. The plan sets the goal that by 2020, China's total value of its domestic navigation satellite industry will reach RMB 400 billion ($62.2 billion), four times China's current market value. Furthermore, Beidou's domestic market share for domestic satellite navigation applications will reach 60 percent (80 percent for unspecified important applications).[620] In most sectors, this would mean a massive transformation of device offerings in China as companies focus on producing Beidou-compatible devices. While some local companies may have an advantage in producing and marketing such devices, this has not been the initial experience of the industry. In fact, in 2014 Samsung of South Korea became the first company to produce a Beidou-compatible mobile phone. It was followed in the same year by Huawei.[621]

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617 State Intellectual Property Office, "卫星导航,也需专利'护航'" [Navigation Satellite Also Needs Patent "Convoy"], July 2, 2014, http://www.sipo.gov.cn/mtjj/2014/201407/t20140702_974175.html.

618 State Council, "关于促进信息消费扩大内需的若干意见" [State Council Opinion on Promoting Information Consumption and Expanding Domestic Demand], Doc. No. 32, August 14, 2013, http://www.gov.cn/zwgk/2013-08/14/content_2466856.htm; State Council, "国家卫星导航产业中长期发展规划" [Medium- and Long-Term Development Program for National Navigation Satellite Industry], Doc. No. 97, September 26, 2013, http://www.gov.cn/zwgk/2013-10/09/content_2502356.htm.

619 State Council, "国务院关于印发"十二五"国家战略性新兴产业发展规划的通知" [State Council Issues Notices on "12th Five Year Program" on National Strategic Emerging Industry Development], Doc. No. 28, July 9, 2012, http://www.gov.cn/zwgk/2012-07/20/content_2187770.htm.

620 "国务院印发国家卫星导航产业中长期发展规划" [State Council Issues National Navigation Satellite Industry Medium- and Long-Term Development Plan], 新浪财经 [Sina Finance], October 9, 2013, http://finance.sina.com.cn/chanjing/cyxw/20131009/103116931925.shtml.

621 China National Space Administration, "北斗导航系统的应用前景" [Application Prospects for Beidou Navigation System], May 5, 2015, http://www.cnsa.gov.cn/n1081/n7619/n7875/697846.html.

Table 10. Chinese state policies concerning the satellite navigation and service industry

Regulation/Policy	Issue Date	Department	Main Content
Guide to High-Technology Industrialization Key Sectors for Current Priority Development 当前优先发展的高技术产业化重点领域指南	Jan. 2007	NDRC, MOST, MOFCOM, SIPO	Places priority development status on satellite navigation receiver chip set and embedded software, satellite navigation system location-based information and application services terminal, vehicle communication navigation system, personal navigation information terminal, and integrated application platform of earth observation satellite system.
Opinions on Promoting the Development of the Satellite Application Industry 关于促进卫星应用产业发展若干意见	Nov. 2007	NDRC, COSTIND	Promote the rapid development of satellite navigation and location-based services industry, especially to promote the industrial development of satellite navigation and satellite navigation terminal equipment, improve the basic support for the application of satellite navigation, promote the industrialization of satellite navigation terminal equipment, and promote the development of satellite navigation industry.
Notice on Organizing Applications for Satellite High-Technology Industrialization Projects 关于请组织申报卫星应用高技术产业化专项的通知	Jan. 2008	NDRC	Decision to organize and implement the application of satellite high-technology industry to make the Beidou satellite navigation system compatible with the GPS/GLONASS/terminal module, miniaturization, low power technology and system application development and industrialization, focusing on promoting the car front, dual frequency measurement, high sensitivity, GNSS and cellular phone integration.
Supplementary Notice Concerning 2009 Continue Organizing and Implementing Applications of Satellite High-Technology Industry 关于 2009 年继续组织实施卫星应用高技术产业化专项的补充通知》	Feb. 2009	NDRC High-Technology Industry Division	Placed focus and promised support to satellite navigation application and remote sensing fields.
Decision of the State Council on Accelerating the Development of Strategic Emerging Industries 国务院关于加快培育和发展战略性新兴产业的决定	Oct. 2010	NDRC	Listed five key areas of future high-end equipment manufacturing, including satellite manufacturing and applications.
Notice on Strengthening the Dynamic Supervision of Road Transport Vehicles 关于加强道路运输车辆动态监管工作的通知	Mar. 2011	MOC, MPS, State Administration of Work Safety, MIIT	Requires installation and use of satellite positioning device with driving record function to increase supervision of all travel rental cars, three or more class line passenger buses and road vehicles that transport hazardous chemicals, fireworks, and civil explosives.

Table 10. Chinese state policies concerning the satellite navigation and service industry (continued)

Regulation/Policy	Issue Date	Department	Main Content
12th Five-Year Plan for Informatization of Highway and Waterway Transportation 公路水交通运输信息化"十二五"规划)	Apr. 2011	Ministry of Transport	Actively promote the second generation satellite navigation system in the field of traffic safety, ship navigation, transportation infrastructure, highway transportation and public transportation.
Notice on Accelerating the Implementation of the Key Transport Process Monitoring and Management Service Demonstration System 关于加快推进"重点运输过程监控管理服务示范系统工程"实施工作的通知	Dec. 2012	Ministry of Transport	Requires Tianjin, Hebei, Jiangsu, Anhui and other 9 provinces to install Beidou/GPS dual mode vehicle terminals on more than 80 percent of "two passenger and dangerous" vehicles by March 2013.
12th Five-Year Plan for National Indigenous Innovation Capacity Building 十二五国家自主创新能力建设规划	Jan. 2013	State Council	Satellite mobile communications to be included as focus area of the strategic emerging industries.

Source: Tian Yu, "北斗"迈向全球尚未可期 ['Beidou' World Expansion is Still Difficult to Expect], 凤凰周刊 [*Phoenix Weekly*], April 27, 2015, http://www.ifengweekly.com/detil.php?id=1855.

Technologically, the plan emphasizes the need to increase development of core microchips, software, and other high-end products. The plan further promotes policies to export China's Beidou navigation systems. Other policies are designed to encourage mass consumer adoption through improvement of domestic user location reporting systems and privacy protection policies. To expand Beidou's global reach, the plan encourages improvement of financial and taxation policies to enable domestic firms to "go out" and expand to international markets, although specifics on the types of financial or taxation policies were not provided.[622] The August 2013 Opinions of the State Council on Promoting the Information Consumption and Expanding Domestic Demand also identifies Beidou applications as nationally important plans.[623]

Around the same time that these two policies were issued, it was announced that NDRC, MOST, MIIT, and other government agencies were collaborating to work out the details of the Opinions on Promoting the Development of the Beidou Satellite Navigation Industry, which is intended to provide further policy guarantees for the development of related industries.[624] To date, however, this document has not been made public.

To further encourage adoption of Beidou in China, policies have required the installation of Beidou or Beidou/GPS dual-mode vehicle terminals in vehicles that may present an increased public danger on roads, such as large passenger buses and transport vehicles carrying dangerous goods. The notices have stressed that the installation of the systems is to track potentially dangerous behavior

[622] State Council, "国务院办公厅关于印发国家卫星导航产业中长期发展规划的通知" [Notice from Office of the State Council Regarding Issue of National Satellite Navigation Industry Medium- and Long-Term Development Plan], October 9, 2013, http://www.gov.cn/zwgk/2013-10/09/content_2502356.htm.
[623] State Council Information Office, "News Release at the Press Conference of the State Council Information Office," December 27, 2013, http://press-conference3.beidou.gov.cn/news002.html.
[624] Ibid.

by drivers. However, by regulating that the terminals must be able to receive Beidou signals, it also supports the market for China's domestic technology. For example, one December 2012 policy requires that at least 80 percent of "two passenger and dangerous" vehicles in thirteen provinces, including Tianin, Hebei, Jiangsu, and Anhui, install Beidou/GPS dual-mode vehicle terminals by March 2013.[625]

Implications for the United States

China is pushing to indigenize its domestic satellite navigation industry, which has been dominated so far by GPS. With Beidou available nationwide, China is seeking increase adoption of Beidou as the country's primary GNSS supplier and also encourage development of domestic downstream providers of GNSS services. Given the overwhelming market position of GPS in China, however, it will likely take many years for Beidou to be the dominant navigation system, even within China. Like the United States' development of GPS, China's primary motivation to develop Beidou is national security, and it will continue to receive strong state support both in military and civilian applications.

While its crowding out of GPS in China's domestic economy may be gradual, Beidou is expected to eventually be a strong and equal competitor to GPS. As early as 2012, the Chinese government was lauding its international competitiveness. At that time, the director of China's Satellite Navigation System Management Office stated that the Beidou system's precision and accuracy was comparable to GPS, and the entire system was stable.[626] To date, however, while Beidou has gained in accuracy and reliability with the addition of more satellites and increased technology, GPS is still currently seen as the more accurate and reliable system.

A major area of competition will be in foreign markets, particularly regional neighbors. Countries with close ties to the United States and problematic relations with China will be hesitant to fully adopt Beidou as their national navigation system, but many other countries, particularly regional countries, will see Beidou as a viable option and competitor to GPS. Through its stated goals and policies, China has indicated that it will actively promote Beidou in these countries. This will initially target Eurasian and OBOR countries. As of 2020, however, Beidou is expected to have global coverage, and China will promote Beidou more broadly.

On the downstream side of equipment and applications, international, and particularly US, firms have created a strong presence in the domestic GNSS landscape. The established market position of these firms is unlikely to immediately dwindle with the introduction of Beidou. Indeed, as seen in 2014, Samsung, a foreign company, was the first to market a Beidou-compatible mobile device. No current written policies or plans have indicated that this segment of the market will discriminate against foreign companies. However, with more applications using Beidou, US suppliers can expect stronger competition from Chinese companies. As with current regulations regarding the installation of Beidou terminals in vehicles, it is likely that many of the new Beidou terminals will be dual mode to allow use of both Beidou and GPS. This may create additional opportunities for US companies. Based on experience in other sectors, however, and consistent with Beidou's ties

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[625] "北斗导航民用示范工程启动 9 省市须强制安装北斗终端" [Beidou Navigation Civilian Demonstration Work Launches; Nine Provinces and Cities Must Install Beidou End Terminals], 中安网 [China Security Net], January 29, 2013, http://www.bwgc.com.cn/zxdt8.html.

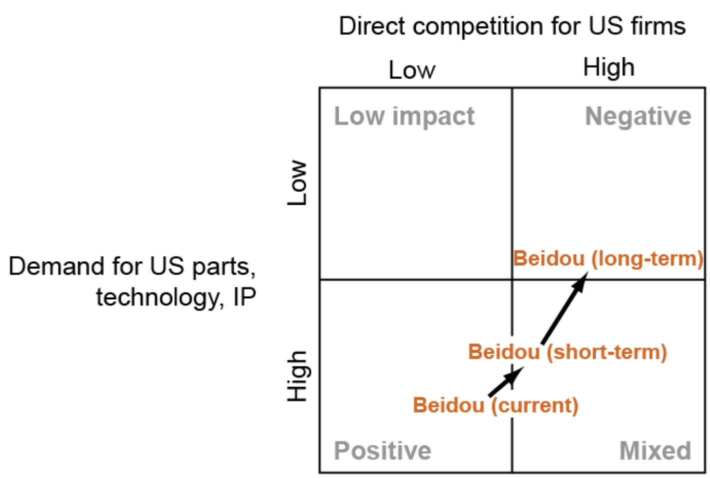
[626] Ibid.

to national security, it is likely that the financial and tax incentives stated in the 2013 Medium- and Long-term Development Plan for National Navigation Satellite Industry will be given primarily to local Chinese companies.

In its initial stages, government-mandated adoption of Beidou will also likely continue. It is uncertain whether this will eventually transition to encouragement of solely Beidou-compatible devices, but there does not seem to be an immediate need for this to happen.

In the end, there will be both positive and negative implications for US economic competitiveness. On the national security side, GPS and US suppliers will be replaced with local suppliers to indigenize equipment and provide "secure and controllable" options for government and military users. It is unclear how broadly this will be applied to the civilian market. Current indications are that there will still be a significant demand for US parts, technology, and IP, particularly in the short term. The long term will likely see at least a measured increase in competition among Chinese suppliers and a replacement of some of the US-supplied market by Chinese suppliers. This shift in implications for US economic competitiveness is illustrated in Figure 17.

Figure 17. Outcomes of Chinese investment in global navigation satellite systems for US firms



Integrated Circuits

Integrated circuits (IC), also known as computer chips and semiconductors, are small electronic devices made up of a collection of resistors, capacitors, and transistors on a small chip. ICs are used in nearly all modern electronic devices and have become the foundation of the computing revolution. Due to its size and position as the leading assembler of and market for of IT-related products, China made up nearly 57 percent of global market demand for semiconductors in 2014.[627] China, however, also imports the vast majority of chips. In 2014, China imported $231.3 billion worth of computer chips—more than it spent importing oil.[628] Economic concerns, coupled

[627] "China's Impact on the Semiconductor Industry: 2015 Update," accessed June 23, 2016, http://www.pwc.com/gx/en/industries/technology/publications/china-semiconductor-consumption-market.html.
[628] Allen Lu, "Overview of China Semiconductor Industry," April 23, 2015, http://www.semi.org/en/sites/semi.org/files/data15/docs/China_IC_industry_overview2015-4-23.pdf.

with national security concerns raised by Edward Snowden's allegations of US cyber espionage, have provided impetus for China to prioritize support for the development of an internationally-competitive domestic IC industry that can serve its economic and national security needs. In current Chinese IC and related policy documents, "controllable and secure" is a common reference. "Secure" often means a Chinese product and almost always implies an implicit demand for Chinese products, although in this context there is much uncertainty about the meaning of both "controllable" and "secure"—and how Chinese policymakers will implement these needs.[629]

Market Characteristics

The global market for semiconductors has increased at an annual average rate of 11.5 percent since 1994. It reached $335.8 billion in 2014 and is forecast to reach $347 billion in 2015.[630] US semiconductor producers remain the market leaders with 51 percent of the market in 2014, followed by Korea (17 percent), Japan (12 percent), Europe (8 percent), Taiwan (7 percent), and China (4 percent). Semiconductors are the third major export for the United States at $42 billion, behind commercial aircraft and automobiles. The Asia-Pacific market is the largest and fastest growing market for semiconductors and has quadrupled in size from $39.8 billion in 2001 to more than $194 billion in 2014. Due to the intense competition over manufacturing faster and more complex chips, heavy investment in R&D remains a critical component of maintaining market lead. Spending on semiconductor R&D by US companies, for example, increased at an average annual rate of 33 percent between 1993 and 2013, resulting in the US semiconductor industry overall leading other industries overall in R&D expenditures as a percentage of sales at 18.9 percent.[631]

Technology Levels

China's IC industry lags behind leading global manufacturers due to numerous structural deficiencies. China's leading foundry, Semiconductor Manufacturing International Corporation (SMIC), is around two generations behind global leaders Intel, Samsung, and Taiwan Semiconductor Manufacturing Company (TSMC).[632] Most of China's IC industry focuses on low-end applications for mature and standardized products, such as chips in the 160−180 nm range that require less R&D and smaller, less expensive research teams.[633]

According to a senior MIIT official, the majority of companies in China's IC industry are "too small to invest in sophisticated design capabilities" that could establish China as a world leader in

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[629] Paul Mozur, "Jitters in Tech World Over New Chinese Security Law," *New York Times*, July 2, 2015, http://www.nytimes.com/2015/07/03/business/international/jitters-in-tech-world-over-new-chinese-security-law.html.

[630] "The US Semiconductor Industry: 2015 Factbook," Semiconductor Industry Association, http://www.semiconductors.org/clientuploads/Industry%20Statistics percent20Statistics/2015%20Factbook%202 percent20Factbook percent202.0%20-%2002032015 percent20- percent2002032015.pdf.

[631] Ibid.

[632] Paul Mozur, "Qualcomm in Venture with Chinese Chip Maker," *New York Times*, June 23, 2015, http://www.nytimes.com/2015/06/24/business/international/qualcomm-in-venture-with-chinese-chip-maker.html.

[633] Richard Goering, "China Fabless Semiconductor Panel: Don't Pack Your Bags Just Yet," June 14, 2014, http://community.cadence.com/cadence_blogs_8/b/ii/archive/2014/06/18/china-fabless-semiconductor-panel-don-t-pack-your-bags-just-yet.

computer chips.[634] As of June 2014, China had 632 fabless companies (companies that specialize in IC design but contract out production), with just 124 having revenues of more than RMB 100 million ($15.5 million) and 223 losing money.[635] Exacerbating this trend is a cultural predilection against mergers due to a belief that getting bought out is a sign of failure.[636] Rather than spurring competition, the large number of small firms with low returns impedes the financing necessary for the type of R&D necessary to enter into leading-edge chip manufacturing. SMIC's 2013 record profit of $170 million, for instance, is paltry when compared to the $5 billion a month it would need to manufacture 12-inch 28 nm chips. By comparison, during the same time period TSMC, the world's largest dedicated independent semiconductor foundry, posted a net profit of $6.2 billion that allowed it to cover its investments for more than six months.[637]

The requirement to finance large projects has become especially important due to the increasing costs for IC design and process technology, but more financing than Chinese companies can currently muster is required to enter into the level of world-class IC manufacturing. According to Wei Shaojun, director of the Institute of Microelectronics at Tsinghua University, the smaller market for these costlier, but more capable chips will make capturing market share increasingly important. According to Wei, "Capacity is king. If Chinese chip designers cannot squeeze into the global top 10, they will have trouble securing capacity."[638]

A final factor holding back China's IC industry is workforce quality and size. Engineers are paid 13 percent more in China, but are also 20 percent less efficient. Furthermore, China's semiconductor industry only employs 72,000 people, and only 4,000−5,000 engineering graduates go into microelectronics annually.[639]

As a result, China's IC industry faces significant hurdles to becoming a world leader. Dieter Ernst, senior fellow at the East-West Center, sees China's IC industry lagging far behind with few prospects of significantly narrowing the gap with the likes of the United States, Japan, the European Union, Taiwan, and Korea. His assessment is that, "there is no Chinese IC design company that might be able to challenge current global industry leaders."[640] Limin He, a corporate vice president at Cadence Design Systems, a US semiconductor design company, agrees, stating that "the center of gravity for chip design has not shifted to China. Despite a few well-known Chinese companies like HiSilicon and Spreadtrum, the top ten fabless companies are all in the United States, Taiwan, or Japan. These companies are spending billions of dollars to invest in new development."[641]

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[634] USITO interview with Miao Wei, director of the Department of Informatization, MIIT, on the background, significance, and key points from the "Guidelines" June 25, 2014, 3, quoted in Dieter Ernst, "From Catching Up to Forging Ahead? China's Prospects in Semiconductors," East-West Center Working Paper, Innovation and Economic Growth Series, November 2014, 15.
[635] Goering," China Fabless Semiconductor Panel: Don't Pack Your Bags Just Yet."
[636] Ibid.
[637] USITO interview with Miao Wei in Ernst, "From Catching Up to Forging Ahead?" 15.
[638] Hsiao-wen Wang, "China's Semiconductor Grab," *Commonwealth Magazine,* August 21, 2014, http://english.cw.com.tw/article.do?action=show&id=14830&offset=3.
[639] Goering, "China Fabless Semiconductor Panel: Don't Pack Your Bags Just Yet."
[640] Ernst, "From Catching Up to Forging Ahead? China's Prospects in Semiconductors," 7.
[641] Goering, "China Fabless Semiconductor Panel: Don't Pack Your Bags Just Yet."

Policy Measures

In June 2014, the Chinese government issued the Guidelines on Developing and Promoting the National Integrated Circuit Industry (国家集成电路产业发展推进纲要), calling the IC industry a "strategic, foundational, and leading industry" that is the "core of the information technology industry that supports societal and economic development and maintains national security." This was only the third time that China's State Council had issued a targeted plan for the IC industry. It furthermore marked a shift from earlier plans that had focused on cultivating the demand side of the industry to a pointed focus on building up China's supply side of the IC industry.[642] The guidelines designated the development of an advanced IC industry an important element of China's goal to achieve self-sufficiency in technologies through the Made in China 2025 and Internet Plus plans, as discussed previously. The guidelines were issued to correct the deficiencies in China's IC industry by making it able to better respond to a rapidly changing global IC industry that has seen increasingly large investments, market share being concentrated in a smaller group of companies, and an explosion in mobile technologies, cloud computing, networking, and big data.[643]

Following recent government emphasis on increasing the role of the market in driving innovation, the guidelines call for a market-based approach that emphasizes consumer and national security demand to build an industrial chain that goes from "chip to software to hardware to system to information service."[644] The approach is intended to strengthen the role of enterprises in developing hardware and software by strengthening innovation in the design of ICs and the development of software. Finally, it emphasizes utilizing global resources, promoting innovation along all elements of the industrial chain, and strengthening international cooperation.

The Chinese government laid out a series of goals that are intended to enable the semiconductor industry to reach international levels by 2030. By 2015, the industry was to have made clear progress in terms of revenue and technology and in developing industry regulations in regards to investment and the policy environment. By the end of 2015, revenue from China's IC industry was expected to exceed RMB 350 billion ($54.43 billion). Actual revenue in 2016 exceeded this goal to reach RMB 361 billion ($56.14 billion).[645] In terms of technology, goals include that the industry will approach international levels in mobile intelligent communications (smart phones) and network communications and will achieve production scale of 32/28 nm manufacturing processes. In addition, middle- and high-end packaging and testing will constitute more than 30 percent of sales and the application of 65/45 nm critical equipment and 12-inch wafers will be achieved.[646]

The guidelines dictate that by 2020 China's IC industry should begin to close the gap with international technology levels, with an annual growth rate exceeding 20 percent. According to one

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[642] Interview with semiconductor industry representative, January 14, 2016.
[643] Ibid.
[644] "国家集成电路产业发展推进纲要" [Guidelines on Developing and Promoting the National IC Industry], June 24, 2014, MIIT website, http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/16044261.html.
[645] Zhu Shenshen, "More Cash Promised to China's IC Fund," *Shanghai Daily*, March 16, 2016, http://www.shanghaidaily.com/business/it/More-cash-promised-to-Chinas-IC-fund/shdaily.shtml.
[646] Ibid.

analysis, China plans to produce half the semiconductors it consumes by 2020—up from 8.9 percent in 2014—with demand mainly coming from smart phones.[647] IC design for mobile smart terminals, networked communications, cloud computing, networks, and big data will reach international levels and an initial industrial ecosystem will be formed. Large-scale manufacture of 16/14 nm chips will be achieved and packaging and testing will reach international levels. Critical equipment and materials, however, will continue to be procured from the international market.

By 2030 China's IC industry will have largely reached international levels, with a few enterprises entering the top tier of international companies.[648]

To oversee this plan, the guidelines call for the establishment of a State IC Industry Development Leading Small Group (集成电路产业发展领导小组) that will be responsible for coordinating the actions of industry players and resolving important, yet unspecified, issues. An advisory committee will be created to provide expertise to the LSG and assess the effectiveness of IC industry reforms.[649]

To reach these goals, China must expand its industry in terms of both production capacity and level of technology. As of 2014, however, China had just two companies whose revenues exceeded $1 billion: HiSilicon Technologies and Spreadtrum Communications.[650] To fund the expansion of the industry, China set up an RMB 120 billion ($18.66 billion) National Integrated Circuit Industry Investment Fund (国家集成电路产业投资基金) in September 2014. The fund will focus on investment in IC manufacturing, design, packaging, testing, and equipment, with 60 percent of the funding being devoted to manufacturing. The fund will invite large enterprises, financial institutions, and private investment funds (known as "societal funds") to invest. The fund's founding members include the China Development Bank Capital Corporation, China Tobacco, China Electronics Technology Group, local governments, private enterprises, and financial institutions.[651] The fund became the second largest investor in SMIC in February 2015 when it invested $400 million in the company.[652]

This national fund is made up of approximately $25 billion from eleven local and provincial funds that have been established in cities such as Beijing, Shanghai, Anhui, Shandong, Tianjin, Wuhan, and Shenzhen. Altogether by the end of 2015, these equity funds were expected to exceed RMB

[647] Handel Jones, "China Wants to Be No. 1," *EE Times*, August 20, 2014, http://www.eetimes.com/author.asp?section_id=36&doc_id=1323593.
[648] Guidelines on Developing and Promoting the National IC Industry.
[649] Ibid.
[650] Ibid.
[651] Jonathan Davis, "Industry Luminaries Outline China's Semiconductor Growth," *Semiconductor Engineering*, April 27, 2015, http://semiengineering.com/industry-luminaries-outline-chinas-semiconductor-growth-prospects/; and "National Investment Fund to Benefit China's IC Industry."
[652] Davis, "Industry Luminaries Outline China's Semiconductor Growth"; Peter Clark, "China Pumps Cash into SMIC," *IHS Electronics 360*, February 18, 2015, http://electronics360.globalspec.com/article/5020/china-pumps-cash-into-smic.

200 billion ($31.1 billion).[653] Private equity investment funds, on the other hand, will be responsible for just 36 percent of the National Investment Fund, indicating that most funding will be from government-directed entities.[654]

Indeed, the National IC Fund, while registered and billed as a private equity fund, remains largely in control of government actors. Many of the same individuals that previously made national IC policy in MIIT's Electronic Information Division are part of the management of the National IC Fund. They are reportedly filling the same policymaking goals there as they were at MIIT, including drafting of the 13th FYP. Thus, while China advertises the fund as privately run and nongovernmental, it is viewed by many industry experts as an arm of the Chinese government that will primarily be used to push forward China's IC industry goals and priorities. In this way, the fund can be viewed as an attempt to avoid WTO agreements on government financing of industry. To date, the fund has made 20–30 investments in Chinese companies. US and foreign firms are not explicitly excluded from access to its funds, but they are unwilling to comply with requirements for technology transfer and other coercive measures to qualify.[655]

The IC industry is also expected to receive additional financial support. China's Export-Import Bank, China Development Bank, and other commercial banks will continue to increase their lending. Preferential tax policies will also be provided to enterprises engaged in packaging, testing, and special materials and will continue to provide duty-free status to large IC manufacturing equipment and critical components that can be sourced domestically.[656]

Implications for the United States

The implications for the United States of an internationally competitive Chinese semiconductor industry are potentially significant, especially given the dominant position of US industry and the size of the China market. Semiconductors are the third largest export for the United States after aircraft and automobiles at $43 billion, and China is the top export market for semiconductor firms headquartered in the United States.[657] US companies such as Intel, Qualcomm, and AMD, for example, are some of the top exporters of semiconductors to China, ranking first, fourth, and eighth, respectively.[658] Moreover, the China market can represent a substantial portion of these companies' revenue. Intel, for example, draws more than $11 billion, or 19.7 percent, in revenue from the China market out of a total net revenue of $55.87 billion.[659] Qualcomm is even more reliant, drawing 53 percent of its revenue from China.[660]

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[653] PriceWaterhouse Coopers, "A Decade of Unprecedented Growth: China's Impact on the Semiconductor Industry 2014 Update," January 2015, 6.
[654] Ernst, "From Catching Up to Forging Ahead? China's Prospects in Semiconductors," 21.
[655] Interview with semiconductor industry representative, January 14, 2016.
[656] Guidelines on Developing and Promoting the National IC Industry.
[657] 2015 Semiconductor Industry Factbook; Indrek Grabbi and Dorothea Blouin, "2015 Top Markets Report Semiconductors and Semiconductor Manufacturing Equipment: A Market Assessment Tool for US Exporters," International Trade Administration, July 2015, http://trade.gov/topmarkets/pdf/Semiconductors_Top_Markets_Report.pdf.
[658] "China's Impact on the Semiconductor Industry: 2015 Update."
[659] Intel, "2014 Annual Report," 108, http://www.intc.com/intel-annual-report/2014/files/Intel_2014_Annual_Report.pdf.
[660] "Qualcomm Incorporated Form 10-K for the Fiscal Year Ended September 27, 2015," http://investor.qualcomm.com/secfiling.cfm?filingID=1234452-15-271&CIK=804328.

Three factors will play a role in the shift of semiconductor design and manufacturing activity to China. The first is China's position as the largest market for personal computers, tablets, and cell phones, all of which require computer chips.[661] China's market size can enable China to influence technology development through either the "invisible hand" of the market place or through direct government policy.[662] China's position as the largest semiconductor market places pressure on top IC manufacturers to enter into cooperative agreements with Chinese companies and increase their manufacturing presence in China. TSMC, the world's largest foundry, announced its intention to invest $3 billion to build a 12-inch wafer fab and a design center in China.[663] Another Taiwan firm, United Microelectronics Corporation, invested $1.35 billion in a joint venture with the Xiamen municipal government Fujian Electronics and Information Group to manufacture computer chips.[664] In October 2015, Intel announced that it would spend at least $3.5 billion and possibly as much as $5.5 billion to convert a Chinese semiconductor manufacturing plant to make "leading-edge" nonvolatile memory chips. This announcement reverses an earlier plan by Intel that limited the plant to making chips at least two generations behind chips at its other factories.[665] After being fined $975 million for antitrust violations in February 2015, Qualcomm announced a partnership with Chinese semiconductor manufacturer SMIC in July 2015 to establish a joint venture to mass produce chips using 14 nm process technology by 2020.[666] These agreements will help raise the low technology levels of Chinese semiconductors and enable Chinese manufacturers to become more competitive, especially in the Chinese domestic market.[667]

A second factor is the acquisition of foreign semiconductor firms. According to Dieter Ernst, "Mergers and acquisitions, both among Chinese companies and with global industry leaders, are now considered to be an important shortcut to strengthen financial resources, as well as management and technological capabilities."[668] Indeed, driven by changing market dynamics, the global IC industry experienced a record number of M&A by market value in 2015, topping $80 billion. Established market leaders acquired rivals to respond to the growing importance of the IoT, which is expected to increase demand for semiconductors, and to a slow growth market for chips for other applications, which is causing IC manufacturers to turn their attention to a variety of chips and applications rather than concentrate on one growth sector.[669]

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661 Ernst, "From Catching Up to Forging Ahead? China's Prospects in Semiconductors," 21.
662 USITO interview with Miao Wei in Ernst, "From Catching Up to Forging Ahead?" 24.
663 Alan Patterson, "TSMC Aims to Build Its First 12-inch Fab in China," *EETimes*, December 7, 2015, http://www.eetimes.com/document.asp?doc_id=1328431.
664 Rick Merritt, "UMC Joins $6.2B China Foundry," *EETimes*, October 9, 2014, http://www.eetimes.com/document.asp?doc_id=1324238.
665 Don Clark, "Intel to Spend at Least $3.5 Billion Converting China Plant for Memory Chips," *Wall Street Journal*, October 20, 2015, http://www.marketwatch.com/story/intel-to-spend-at-least-35-billion-converting-china-plant-for-memory-chips-2015-10-20.
666 Michael Kan, "Qualcomm Partners with Large Chinese Foundry on Chips," *PC World*, June 23, 2015, http://www.pcworld.com/article/2940012/qualcomm-partners-with-large-chinese-foundry-on-chips.html.
667 Jon Russel, "Intel Invests $67M into 8 Chinese Companies, Including Segway Owner Ninebot," *Techcrunch*, September 16, 2015, http://techcrunch.com/2015/09/16/intel-invests-67m-into-8-chinese-companies-including-segway-owner-ninebot/; Mozur, "Qualcomm in Venture with Chinese Chip Maker."
668 Ernst, "From Catching Up to Forging Ahead? China's Prospects in Semiconductors," 17.
669 Dylan McGrath, "IC Merger Mania Hits Fever Pitch," *EETimes*, December 2, 2015, http://www.eetimes.com/author.asp?section_id=36&doc_id=1328395.

Chinese companies flush with cash from government-led investment funds have also played a role. Chinese companies are expected to spend $100 billion over the next five years on domestic and overseas acquisitions to grow the IC industry by more than 20 percent per year.[670] Tsinghua Unigroup alone announced more than $20 billion in investments in 2015, including more than $2 billion for stakes in two Taiwanese chip-packaging companies and $3.78 billion for a stake in US disk-drive maker Western Digital.[671] In April 2015, Chinese entities Hua Capital Management, CITIC Capital Holdings, and GoldStone Investment bought OmniVision Technologies, a maker of chips for smartphone and tablet cameras.[672] In May 2015, Chinese investment firm JAC Capital offered to pay $1.7 billion for the radio-frequency amplifier business NXP Semiconductor, a Dutch company. Also in 2015, Fairchild Semiconductor International received an unsolicited acquisition offer of $2.46 billion from a group led by China Resources Holdings and Hua Capital Management that beat a previously accepted offer by US semiconductor supplier ON Semiconductor Corporation.[673]

A third factor is the increasing specialization of the semiconductor industry. Only large semiconductor companies like Intel and Samsung combine IC design and manufacturing. Most other companies, have separated the two businesses, with manufacturing being transferred to Asia along with important segments of electronics system and IC design.[674] This disaggregation of the value chain in the semiconductor industry potentially lowers barriers to entry for Chinese firms, who may need to only excel in one aspect of IC chip production rather than the entire industrial chain. According to Leo Li, the CEO of China's leading IC design company Spreadtrum, "the availability of IC design tools, semiconductor fab services, and open-source smartphone software [Android] allows Chinese firms to circumvent their weak spots and develop their strengths in hardware, IC design, and integration."[675]

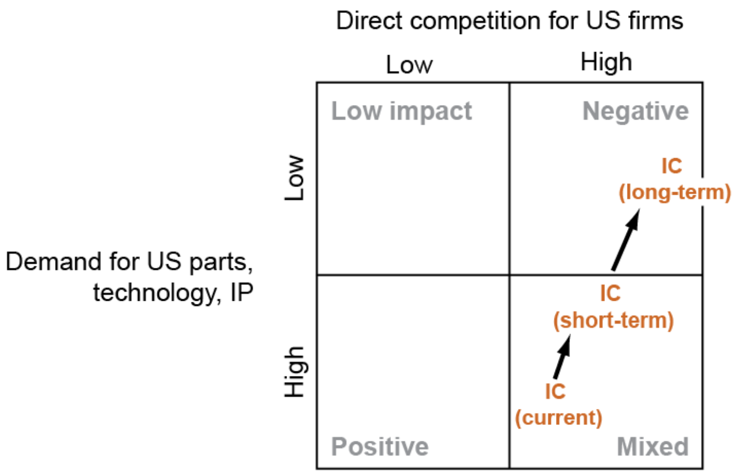
The confluence of these factors will most likely pose challenges for US semiconductor firms as they attempt to maintain market share and revenue in the Chinese market, especially as US companies are the dominant players in the market. Despite these factors, the US semiconductor industry will likely remain at the cutting edge of IC technology for some time and will likely remain the dominant player of leading edge chips in the Chinese market even if market share is eroded, especially if US industry maintains its commitment to R&D.

Notwithstanding the strong position of US firms in the Chinese market, many firms currently face strong opposition in promoting their business in China, and over the past two years since China's

[670] Pete Carey, "More Deals Ahead? China Fund Buys Silicon Valley Chip Maker," *San Jose Mercury News*, April 5, 2015, http://www.mercurynews.com/business/ci_27854216/more-deals-ahead-china-fund-buys-silicon-valley.
[671] Eva Dou, "China's Tsinghua Unigroup Plans to Buy Stakes in Taiwan Chip Firms," *Wall Street Journal*, December 11, 2015, http://www.wsj.com/articles/chinas-tsinghua-unigroup-plans-to-buy-stakes-in-taiwan-chip-packaging-companies-1449829062.
[672] Supantha Mukherjee, "OmniVision to Be Bought by Chinese Investors in $1.9 Billion Deal," Reuters, April 30, 2015, http://www.reuters.com/article/us-omnivision-techs-m-a-huacapitalmanage-idUSKBN0NL1IP20150430.
[673] Alex Sherman, "Fairchild Says China Resources Offer Seen 'Superior' to ON," *Bloomberg Business*, January 4, 2016, http://www.bloomberg.com/news/articles/2016-01-05/fairchild-said-planning-to-say-china-resources-bid-may-top-rival.
[674] Ernst, "From Catching Up to Forging Ahead? China's Prospects in Semiconductors," 10.
[675] Ibid.

introduction of its Guidelines on Developing and Promoting the National Integrated Circuit Industry and National IC Investment Fund, there has been an escalation of funds going toward China's domestic IC industry that makes it a serious competitor to the global industry. For this reason, the current implications for US economic competitiveness from China's state S&T plans are considered mixed. This is expected to become more negative over the short and long term (Figure 18).

Figure 18. Outcomes of Chinese investment in integrated circuits for US firms



Additive Manufacturing (3D Printing)

Additive manufacturing (AM), also called 3D printing, is "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing technologies."[676] In most applications, a digital 3D image is created using a computer-aided design system and divided into numerous layers. A 3D printer then prints successive layers of material and fuses them together to create a single object. The applications are widespread and cover many industries that hope to use AM for different purposes. Almost universally, however, AM allows greater flexibility in design and customization, less scrap, and shorter production cycles.[677]

Most Chinese companies are significantly behind the United States in terms of market share and R&D in the AM industry. Chinese firms and researchers in a few key areas, however, have made considerable progress to suggest that China has the potential to become a serious competitor to the United States. The Chinese government's focus on the AM industry spans at least a decade, but it has received increasing focus in past few years, including an AM-specific national development plan and its inclusion (although without many details) in the Made in China 2025 plan. Many US companies are already collaborating with Chinese counterparts to access the Chinese market and also to increase market share in the United States. As the AM industry develops further, it is expected that competition and collaboration between China and the United States will intensify.

[676] ASTM International, "Standard Terminology for Additive Manufacturing Technologies," Active Standard ASTM F2792, http://www.astm.org/Standards/F2792.htm.
[677] Daniel Cohen, Matthew Sargeant, and Ken Somers, "3D Printing Takes Shape," *McKinsey Quarterly*, January 2014, http://www.mckinsey.com/insights/manufacturing/3-d_printing_takes_shape.

Market Characteristics

Over the past five years, the AM industry has experienced rapid growth, largely due to increased affordability of the technology. This increased affordability has resulted from the increasing maturity of the technology and expanding industrial and consumer demand. Globally, this has meant industry growth of 30–35 percent from 2010 to 2014.[678] In 2014, the industry had its highest growth yet at a CAGR of 35.2 percent, reaching $4.1 billion. This represented an expansion of more than $1 billion from 2013.[679] The United States is the dominant market for 3D printing, with North and South America accounting for 42 percent of 3D printers purchased. European markets account for 31 percent, and the Asia Pacific region accounts for 27 percent.[680]

US and European firms comprise most of the leading players in the industry. The world's two largest firms are Stratasys and 3D Systems, both headquartered in the United States. In 2014, the two companies accounted for 34 percent of the global market share.[681] In 2015, they were expected to account for 57 percent of industry revenue. Both firms' operations cover the whole 3D printing industry chain.[682]

China currently holds a small share of the global market. While some Chinese companies are gaining increasing attention from global investors, none are ranked among leading global players. According to the China 3D Printing Technology Industry Alliance, at the beginning of 2015 the market size of China's AM industry was approximately RMB 3.7 billion ($575.35 million), or about 15 percent of the global total. In 2016, it is expected to rise to RMB 10 billion ($1.55 billion).[683] There are expectations that the market size will reach RMB 20 billion ($3.2 billion) by 2020.[684] These revenues are broken down into printing services (approximately 50 percent), equipment (30 percent), and materials, software and other (20 percent).[685]

Industrial end-user adoption in China, however, is still low. In 2013, the global installed 3D printer base stood at about 200,000, with about 40 percent of those installed in the United States.[686] China currently owns 8.7 percent of the world's 3D printers, an underrepresentation of China's large

[678] Wijaya Ng and Joshua Tan, "Opportunities and Challenges in China's 3D Printing Market," Ipsos Business Consulting, May 2015, http://www.ipsosconsulting.com/pdf/White-Paper-Opportunities-And-Challenges-In-China's-3D-Printing-Market.pdf.

[679] Wohlers Associates, "Wohlers Associates Publishes 20th Anniversary Edition of Its 3D Printing and Additive Manufacturing Industry Report," April 6, 2015, http://www.wohlersassociates.com/press69.html.

[680] Canalys, "3D Printing Market Surpasses US$3.3 Billion Worldwide in 2014," April 2, 2015, http://www.canalys.com/newsroom/3d-printing-market-surpasses-us33-billion-worldwide-2014.

[681] Research and Markets, "Global and Chinese 3D Printing Industry Report 2015," *PR Newswire*, September 7, 2015, http://www.prnewswire.com/news-releases/global-and-chinese-3d-printing-industry-report-2015-300138601.html.

[682] IBISWorld, "3D Printer Manufacturing: Competitive Landscape," IBISWorld Industry Market Research, accessed January 27, 2016, http://clients1.ibisworld.com/reports/us/industry/competitivelandscape.aspx?entid=4428#MSC.

[683] Researchmoz Global, "3D Printing Additive Manufacturing Industry Global and China Market Analysis, Technologies, Shares, Size, Key Players, Growth, and Forecast Report," June 2015, http://www.wdrb.com/story/29240104/3d-printing-additive-manufacturing-industry-global-and-china-market-analysis-technologies-shares-size-key-players-growth-and-forecast-report.

[684] Research and Markets, "Global and Chinese 3D Printing Industry Report 2015."

[685] Ng and Tan, "Opportunities and Challenges in China's 3D Printing Market."

[686] Ibid.

manufacturing base.[687] Indeed, more than two-thirds of the 3D printing equipment manufactured in China is exported.

Beijing Tiertime Technology Co., Ltd. (Tiertime) is Asia's largest 3D printer producer and China's first 3D printer exporter.[688] Since 2012, Tiertime's revenue has grown 40–50 percent annually, reaching RMB 100 million ($15.55 million) in 2014. With total global market revenue reaching $3.3 billion, Tiertime's global market share is nonthreatening at less than 0.5 percent. According to Tiertime, 90 percent of its domestic market share comes from school laboratories where 3D printers are used for educational purposes. The personal consumer market in China is still largely untapped as many Chinese do not see a need to buy a 3D printer for their home or office.[689]

Tiertime receives 70 percent of its revenue from overseas.[690] A significant portion of that revenue comes from exports to the United States. Through its UP! Series 3D printer, Tiertime is competing with dominant US 3D printer retailer Makerbot in the US market, where it licenses its technology to US company Microboards Inc., which manufactures and sells it as the Afinia 3D printer.[691] The printer line has garnered significant attention in the United States, in 2013 receiving Make Magazine's award for "Best Overall Experience."[692] In 2014, Tiertime commanded 8.7 percent of unit shipments in the United States. Stratasys (which owns Makerbot) had a 36.6 percent market share. Other leaders included 3D Systems (17.2 percent), Flashforge (13 percent), and XYZ Printing (6.4 percent).[693]

In the global market, Chinese 3D printing company Hunan Farsoon High-Tech Company signed a strategic cooperation agreement with French company Prodways in September 2015. Based on Farsoon's current machine offerings, Prodways will develop a full range of plastic and metal 3D printers under the "Prodways powered by Farsoon" line. It is expected that the line will compete with US companies that also market their products in Europe. The deal marks the first time that Chinese industrial 3D printing technology has gone abroad. Similar to Tiertime, Farsoon has also marketed its printers in the US market, through Texas-based 3D printing company Varia 3D.[694]

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[687] Davide Sher, "Chinese 3D Printing Market to Triple and Reach $1.6 Billion by 2016," 3D Printing Industry, July 27, 2015, http://3dprintingindustry.com/2015/07/27/chinese-3d-printing-market-set-triple-reach-1-6-billion-2016/.
[688] Shan Ruchao, Guo Qian, and Chen Siwu, "Xinhua Insight: China Taps 3D Printing Consumer Market," *Xinhua News*, September 8, 2015, http://www.globalpost.com/article/6644795/2015/09/08/xinhua-insight-china-taps-3d-printing-consumer-market.
[689] Shan Ruchao et al., "Xinhua Insight: China Taps 3D Printing Consumer Market."
[690] Ibid.
[691] Andrew Wheeler, "Focus on 3D Printing in China: HLH Prototypes," 3D Printing Industry, January 8, 2015, http://3dprintingindustry.com/2015/01/08/focus-3d-printing-china-hlh-prototypes/.
[692] "Afinia H-Series 3D Printer," Printingwith3D, accessed January 27, 2016, http://www.printingwith3d.com/Afinia.html.
[693] Patrick Seitz, "Wearables, 3D Printers to Face Major Upheavals Soon," *Investor's Business Daily*, November 6, 2015, http://www.investors.com/idc-predicts-big-shakeouts-in-wearables-3d-printers/.
[694] "Prodways and Chinese SLS 3D Printer Manufacturer Farsoon Enter Strategic Partnership," September 23, 2015, https://www.3printr.com/prodways-and-chinese-sls-3d-printer-manufacturer-farsoon-enter-strategic-partnership-1330988/; Liu Yinyan and Zhu Luping, "中国工业级 3D 打印首次走出国门" [Chinese Industry-Level 3D Printing Went Abroad for the First Time], Development and Reform Commission of Hunan Province website, September 28, 2015, http://www.hnfgw.gov.cn/gmjj/gyfz/64102.html.

Historically, R&D in China's AM industry has been dominated by a few universities and research institutes. Media reports characterize China's AM industry landscape as consisting of three universities and one enterprise (三校一企): Tsinghua University, Xian Jiaotong University, Huazhong University of Science and Technology, and Beijing Long Yuan–Automated Fabrication System. There are, however, a growing number of players in China's 3D printing industry, including Beijing University of Aeronautics and Astronautics (BUAA) and Tiertime. Most domestic enterprises collaborate with local colleges and universities rather than investing independently in R&D.[695]

The lack of a significant cohort of dominant downstream actors, however, has led to Chinese companies losing some market share to foreign competition. Most of the approximately 100 Chinese companies involved in 3D printing are small and concentrate on consumer desktop printers.[696] Tiertime is perhaps the largest of these, with approximately 150 employees. Given the leading market positions of foreign AM companies, it is natural that they would try to enter the Chinese market. To date, most foreign firms have chosen to use local distributors to market their products within China but have kept manufacturing and other operations outside of China due to IP concerns.[697]

Technology Levels

China lags the United States in overall AM technology levels. It currently ranks third globally in its number of AM patents, although the quality or nature of these patents is uncertain.[698] As already noted, the majority of its industry has focused on the consumer market, with reportedly less than ten Chinese companies working on metallic, industrial-grade printers that require more advanced technology.[699] Bio-printing, a subdivision of 3D printing, is another area receiving attention by Chinese companies. In this area, China is reported to have developed significant independent research and can be considered as one of the leading countries for 3D bio-printing research.[700]

China's most notable success has been in aerospace applications of 3D printing, where it is on the global technological frontier. Aerospace applications are particularly attractive to Chinese policymakers and China's defense industry because of the great potential to upgrade the technological capacity of China's indigenous aviation industry by using AM methods. AM can be used on a multitude of aircraft components to create lighter, more efficient, and more aerodynamic designs. In addition to these benefits, China sees a potential to use AM to create a domestic aero engine, a technology which China's defense industry has failed to develop to international standards.

Supportive of its aim to develop 3D printing aerospace applications, China has invested many resources in developing its capacity in metal alloys such as titanium. For example, the 2012 first prize for the State Technological Invention Award (国家技术发明奖), the highest honor a technological achievement in China can receive, went to a 3D printing team led by Wang Huaming at BUAA. His team used laser metal deposition, a type of AM, to produce a four-meter-long titanium

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695 Ibid.
696 Research and Markets, "Global and Chinese 3D Printing Industry Report 2015."
697 Ng and Tan, "Opportunities and Challenges in China's 3D Printing Market."
698 Sher, "Chinese 3D Printing Market to Triple and Reach $1.6 Billion by 2016."
699 Ibid.
700 Ibid.

alloy primary load-bearing structure that meets aircraft capacity requirements. Chinese sources proudly claim that this is a milestone that the United States has tried but so far failed to achieve.[701] China, of course, is not alone in its investment in this area. Foreign companies, such as GE, also invest heavily and are competing to develop the techniques that will further bring 3D printed components to the aerospace industry.

Policy Measures

AM is included in China's recent Made in China 2025 plan under two categories: new generation information technology and high-end numerical control equipment and robotics. This national attention and support will add to the ongoing help that AM technology has already received for more than a decade from the 973 and 863 plans, the National Natural Science Foundation, and the military.

After a lengthy wait, the Chinese government outlined a three-step AM development plan at the 2012 Additive Manufacturing Technology International Forum and the Sixth National Additive Manufacturing Conference. This includes the creation of a medium- and long-term AM development strategy, the formulation of codes and standards, and increasing efforts to support AM technology development and commercialization through special fiscal and taxation policies.[702]

Media reports in 2013 stated that MOST policy planners were working on a 3D printing strategic plan that was expected to be published in conjunction with the China-sponsored 2013 World 3D Printing Technology Industry Conference held in May 2013.[703] Additionally, the CAE in 2013 launched a one-year investigation to evaluate the future of 3D technology, with the report to be submitted to the State Council in 2014.[704] The status and outcome of these proposed plans and investigations are unknown.

In February 2015, MIIT, NDRC, and MOF jointly issued a two-year plan for China's AM industry titled "National Additive Manufacturing Industry Promotion Plan (2015–2016)" (国家增材制造产业发展推进计划).[705] This is the first government-issued plan in this sector, which had previously been largely driven by private industry.[706] It is noteworthy that the first 3D national plan was issued by MIIT, NDRC, and MOF rather than MOST, and suggests bureaucratic competition between the industrial and the S&T communities.

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[701] Shi Yang, "钛合金 3D 打印 2012 中国第一发明" [Titanium Alloy 3D Printing—2012 First Prize Invention in China], Guanchazhe, January 21, 2013, http://www.guancha.cn/shi-yang/2013_01_21_122111.shtml.

[702] "2012 年增材制造技术国际论坛暨第六届全国增材制造技术学术会议在武汉召开" [2012 Additive Manufacturing Technology International Forum and Sixth National Additive Manufacturing Conference Opens in Wuhan], December 28, 2012, http://www.nmgjxw.gov.cn/cms/zbhygzdt/20121228/7986.html.

[703] "工信部 3D 打印战略规划有望在两会后出台" [Ministry of Industry and Information Technology: 3D Printing Strategic Plan Expected Introduced After the Two Meetings], March 13, 2013, PConline.com.cn, http://office.pconline.com.cn/321/3212623.html.

[704] "China's 3D Tech: From Drawing Board to Real World," January 6, 2013, Hebei.com.cn, http://english.hebei.com.cn/system/2013/01/06/012392838.shtml.

[705] MIIT, "三部门联合印发《国家增材制造产业发展推进计划（2015–2016 年）" [Three Ministries Jointly Issue "National Additive Manufacturing Industry Promotion Program (2015–2016)"], Doc. No. 53, February 11, 2015, http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/16474315.html.

[706] "Chinese Government Unveils 'National Plan' for Development of 3D Printing Industry," 3Ders.org, March 2, 2015, http://www.3ders.org/articles/20150302-chinese-government-unveils-national-plan-for-development-of-3d-printing-industry.html.

The plan aims to develop a functioning and healthy AM industrial system by 2016. The overall goal is the establishment of a complete innovation ecosystem in AM that includes R&D capabilities, software design, printer manufacturing, and service and application centers. China hopes to achieve an indigenous capability in all these areas, with focus directed toward five applications: aerospace/aviation, automobiles, home appliances, culture（文化创意; artifact replication/repair, game animation, film props), and biomedical (生物医疗; tissues, organs, implants).

While China seeks to keep its technology levels in step with international standards, the plan emphasizes the need to take the lead in aerospace/aviation and other direct manufacturing sectors. It encourages Chinese companies to establish joint ventures and facilitate international cooperation, including urging domestic research institutes and private companies to host or be involved in setting international AM standards.

Specific goals of this plan include achieving year-on-year sales growth of at least 30 percent, and spurring the growth of two to three internationally competitive AM enterprises (Table 11). One of the overall goals is to gain control of a large share of the international AM market, although it does not specify the size of the share. The plan goes beyond industry generalities and names specific materials that Chinese industry should target. These include developing indigenous capabilities and domestic additive manufacturers in high-quality titanium alloy, high-strength steel, and high-temperature and high-strength engineering plastic materials by 2016. No explanation is given for the selection of these materials, but each is highly applicable to aerospace applications.

Table 11. Goals of China's National Additive Manufacturing Industry Promotion Plan (2015–2016)

By 2016

- Establish a comprehensive additive manufacturing industrial system
- Keep pace internationally in overall level of technology
- In fields of aerospace/aviation and other direct manufacturing fields reach frontier international level
- Control a large share of international market
- Achieve year-on-year growth in sales revenue of at least 30 percent
- Form 2–3 strong internationally competitive AM enterprises
- Deepen industrial applications
- Establish an additive manufacturing industry association
- Set up 5–6 additive manufacturing technology innovation centers
- Implement indigenous production of titanium alloy, high-strength steel, high-temperature and high-strength engineering plastic materials
- Develop additive manufacturing embedded software systems and hardware interoperability

Policy Measures

- Develop AM development roadmap
- Support R&D of AM technology through national S&T plans (funding and plans)
- Include in scope of major technology equipment import tax policies
- Increase credit support and loan guarantees from banking institutions for AM industry
- Use National Thousand Talents Plan to recruit high-end AM international talent to work in China

The plan recognizes the need for strengthened support from policymakers and urges the MIIT, NDRC, and MOF to jointly produce an AM development roadmap. It also seeks to include support for AM technology R&D in national S&T plans in the form of funding and delineation of specific plans. While leaving out details of specific measures, the plan encourages the industry to be included in import tax policies and encourages banking institutions to increase credit support and loan guarantees for the industry.[707]

The plan further focuses on talent development, calling for the use of China's Thousand Talents Plan (千人计划/海外高层次人才引进计划), a state-led effort to bring Chinese experts overseas back to China, to recruit leading AM talent.[708] In December 2014, the Association of Thousand Talents Plan established the 3D Printing Cooperation and Innovation Group, which included 70 3D printing experts from the Thousand Talents Plan.[709] In sum, however, while the two-year plan provides an important signal of government support, it lacks specific timetables or support policies and instead offers only a broad macro-level perspective and policy prescription for the industry.

At the local level, many Chinese cities are already implementing efforts to develop local AM industries. For example, Zhuhai, Qingdao, Wuhan, and Chengdu have all begun to establish 3D printing industrial parks, giving AM enterprises emerging industry privileges.[710]

Implications for the United States

While China's National Additive Manufacturing Industry Promotion Plan aims to build off China's domestic technology and industrial base, it does not appear at present that there are discriminatory policies or practices directed at US or other foreign AM manufacturers or suppliers. Instead, up to 2014, China's AM industry experienced relatively little government intervention and is quite the nascent industry was driven largely by market concerns. China is seeking to create domestic alliances and strengthen its international position, and this will likely have a positive impact for the US economy. Tan Songbin, chair of the Guangdong Silver Age Science & Technology Company, stated recently that Chinese AM players may turn to overseas M&A to accelerate their development, citing high valuation among peers in the country as a possible impetus.[711]

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[707] "Three Ministries Jointly Issue 'National Additive Manufacturing Industry Promotion Program (2015-2016).'"

[708] Ministry of Industry and Information Technology, "三部门联合印发《国家增材制造产业发展推进计划(2015–2016 年)》" [Three Ministries Jointly Issue "National Additive Manufacturing Industry Promotion Program (2015–2016)"], February 11, 2015, http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/16474315.html.

[709] "海创智库（千人计划）海宁创新创业服务中心推动成立 3D 打印协同创新小组" [HiCreat Think Tank (Thousand Talents Program) Haining Innovation and Entrepreneurship Service Center Promotes Establishment of 3D Printing Cooperation Small Group], Association of Thousand Talents Program, December 15, 2015, http://www.1000plan.org/lianyihui2/news/348.

[710] Wang Xueqing, "3D 打印迎来首个"国家计划" 行业热浪再袭" [3D Printing Ushers in First 'National Plan'], *上海证券报* [*Shanghai Securities News*], March 2, 2015, http://news.cnstock.com/industry/sid_rdjj/201503/3352185.htm.

[711] E. L. Borromeo, "Chinese Government Pushes for 3D Printing Industry Development," Yibada, September 10, 2015, http://en.yibada.com/articles/62073/20150910/chinese-government-pushes-3d-printing-industry-development.htm.

To date, there have been no announced M&A of US companies by a Chinese AM company, but as described earlier, companies such as Tiertime and Farsoon are marketing their 3D printers through US suppliers. In 2013, leading US company Stratasys brought a lawsuit against Afinia for patent infringement. The case is still ongoing, but most observers note that the patent infringements used in the case could be leveraged against any 3D printing company, not just Afinia. The case does highlight, however, the competitive qualities of Tiertime's printers ("cheap and offer significantly more functionality than comparable printers from Stratasys") and Stratasys' fear of the US market being flooded by low-cost Chinese competitors entering licensing agreements with US companies.[712]

To a limited extent, Chinese developments of AM technology may also benefit US workers as Chinese companies seek to establish a presence in the United States. For example, Chinese company Nanjing Zijin-Lead Electrics Company announced in March 2014 that it would open a 3D printing facility in Dothan, Alabama. The facility is targeted at reducing transportation costs and improving customer service in the US market.[713]

US companies are also very active in the Chinese market. A deal between US firm Stratasys's subsidiary Solidscape and Kangshuo Group Company Ltd created China's largest 3D printing service bureau in June 2015 with an 80,000 square-foot facility in Foshan, Guangdong Province, equipped with 100 Solidscape 3D printers. This is the first of what will be 100 similar centers throughout China as part of the deal. Solidscape was selected because of its high precision and leading global reputation.[714] In another case, Hangzhou Shining 3D Technology Company signed a major contract in May 2015 with US subsidiary Autodesk Asia to manufacture and supply 6,300 sets of desktop 3D printers.[715] Currently, all foreign-branded 3D printing equipment sold in China is imported.[716]

In the first M&A deal between a US and Chinese AM firm, 3D Systems announced that it had acquired Chinese company Easyway Design and Manufacturing, a service and sales operation, in April 2015. With offices in Wuxi, Bejing, Guangdong, Chongqing, and Shanghai, this acquisition should enable 3D Systems to further penetrate the Chinese market, opening additional growth.[717] All current indications are that 3D Systems will continue to produce its printers in the United States and export them to China. This case and others illustrate, perhaps surprisingly, a side effect of

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[712] Rakesh Sharma, "Why Stratasys Sued Afinia," *Forbes*, December 3, 2013, http://www.forbes.com/sites/rakeshsharma/2013/12/03/why-stratasys-sued-afinia/#9ad90e3162f8.

[713] "南京紫金立德将在美设立 3D 打印机工厂" [Nanjing Zijin-Lead Will Open Its 3D Printing Factory in the United States], China 3D Printing website, March 29, 2014, http://www.3ddayin.net/news/6243.html; Amy He, "US South Benefitting from China Investment," *China Daily*, July 7, 2014, http://usa.chinadaily.com.cn/2014-07/07/content_17657464.htm.

[714] Michael Molitch-Hou, "Solidscape and Kangshuo Group Open Largest 3D Printing Service in China," 3D Printing Industry, July 23, 2015, http://3dprintingindustry.com/2015/07/23/solidscape-and-kangshuo-group-open-largest-3d-printing-service-in-china/.

[715] "Autodesk Asia Orders 6,300 Desktop 3D Printers from Shining 3D," 3Ders.org, May 7, 2015, http://www.3ders.org/articles/20150507-shining-3d-sells-6300-sets-of-desktop-3d-printers-to-autodesk-asia.html; "先临三维拿下欧特克 6300 台 3D 打印机采购大单" [Shining 3D Got a Massive Order of 6,300 Sets of 3D Printers from Autodesk], 天工社 [marker8.com], May 7, 2015, http://maker8.com/article-3492-1.html.

[716] Ng and Tan, "Opportunities and Challenges in China's 3D Printing Market."

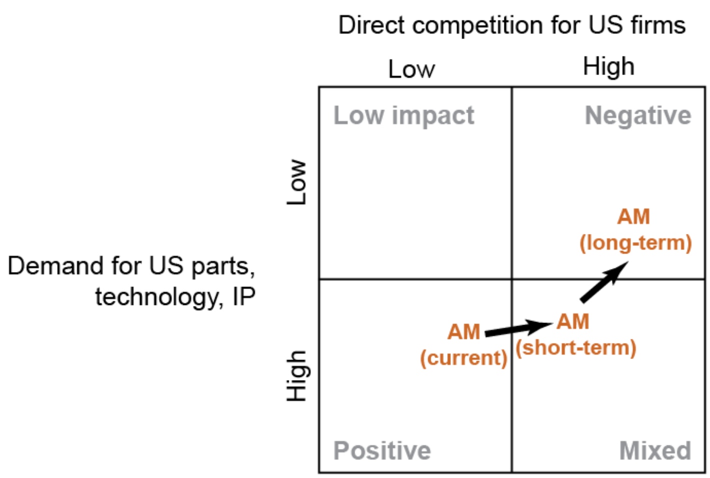
[717] Andrew Wheeler, "3D Systems China Launches with Easyway Group Acquisition," *3D Printing Industry*, April 6, 2015, http://3dprintingindustry.com/2015/04/06/3d-systems-china-launches-with-easyway-group-acquisition/.

Chinese IP concerns, which is that the need to safeguard IP is keeping manufacturing in the United States that might otherwise relocate to China.

Altogether, the AM industry poses a complex set of implications for US economic competitiveness in the industry. The two dominant players in the industry are US firms, and there is little current challenge to their market standing. Chinese firms, however, are advancing in both the development and marketing of competitive 3D printing systems. This is more evident on the consumer 3D printing market than the industrial 3D printing market. Given Chinese firms' early establishment of clear competition with US firms both in the Chinese and US markets, however, it is likely that Chinese firms will continue to grow and compete strategically in both markets.

Due to the large market and cooperative opportunities available for US firms in China and the relatively small presence of Chinese firms in the US market, the balance of current implications for US economic competiveness is viewed as positive (Figure 19). These implications will become more mixed, however, as US firms face more competition from growing Chinese companies. In the long-term, competition for US firms and an increased dominance of Chinese 3D printer manufacturers, especially in the Chinese market, can be expected to have overall negative implications for US firms, production, and workforce. These short-term and long-term outcomes are determined to be more severe compared to the similar industries analyzed (advanced robotics and nanomaterials) because of the speed at which China is developing its AM competitiveness.

Figure 19. Outcomes of Chinese investment in additive manufacturing for US firms



Advanced Robotics

The use of robots and robotic systems is becoming more prevalent in manufacturing and service settings. There are two main types of robots, defined by their intended application: industrial robots for use in industrial automation applications; and service robots, which "perform useful tasks for humans or equipment excluding industrial automation application." Service robots can be further divided into personal service robots (for non-commercial tasks) and professional service robots (for commercial tasks). Service robots are characterized by a degree of autonomy, which means, according to ISO-Standard 8373, that they have "the ability to perform intended tasks based on current state and sensing, without human intervention." This can range from "partial autonomy (including human robot interaction) to full autonomy (without active human robot intervention)."[718]

Since 2013, China has been the largest global consumer of industrial robots. The government continues its push for greater adoption of robots as a way to automate its manufacturing sector as well as to combat rising wages and a shrinking supply of young workers. A significant technology gap means that the Chinese domestic market is currently dominated by foreign players. While US firms are not strong in the production of complete industrial robots, they are significant suppliers of robots parts and related technology. The United States also holds the advantage in next-generation robotics technology, particularly collaborative robots. The rapidly growing Chinese market creates lucrative export opportunities for US robotics firms.

Market Characteristics

According to the International Federation of Robotics, a record number of industrial robots were sold worldwide in 2014, which was 27 percent higher than the year before.[719] China was again by far the largest market destination in 2014, accounting for 25 percent of world sales. About 56,000 units were sold to China, 54 percent more than in 2013.[720] International suppliers delivered about 40,000 units, up 47 percent from 2013, and Chinese suppliers delivered 16,000 units, up 77 percent over 2013.[721] The total supply of industrial robots in China increased by about 36 percent per year from 2008 to 2013.[722] The annual growth rate for robots supplied to the Americas was about 12 percent during the same time period. Robot installations in the United States increased by 6 percent to a peak of almost 23,700 units in 2013.[723]

From 2015 to 2017, global robot installations are estimated to increase by 12 percent on average per year. Due to its relatively low "robot density," China is the rising star of projected growth. As wages rise and supply of young, low-cost workers shrinks, China is looking to replace millions of workers with robots.[724] Total installations of industrial robots from 2014 to 2020 are projected to be around one million units with a market value of around RMB 127.5 billion ($19.83 billion).[725] The automotive, electrical/electronics, rubber and plastics, and metal and machinery industries will continue to be the top consumers of industrial robots globally.[726]

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[718] Quotes from International Federation of Robotics, "Service Robots," accessed October 13, 2015, http://www.ifr.org/service-robots/.

[719] "Global Survey: Industrial Robots Break Worldwide Sales Record—Plus 27 Percent," IFR Statistical Department, March 23, 2015, http://www.worldrobotics.org/index.php?id=home&news_id=281.

[720] Ibid.

[721] "未来 5–8 年内 进口机器人将被国产机器人完成替代" [Domestic Robots Will Replace Imported Robots in the Next 5 to 8 Years], 中国测控网 [ck365.cn], July 31, 2015, http://www.ck365.cn/news/8/38396.html.

[722] "Executive Summary: World Robotics 2014 Industrial Robots and World Robotics 2014 Service Robots," International Federation of Robotics, 2014, http://www.worldrobotics.org/uploads/media/Executive_Summary_WR_2014_02.pdf.

[723] Ibid.

[724] Kelvin Chan, "Robot Revolution Sweeps China's Factory Floors," Phys.org, September 23, 2015, http://phys.org/news/2015-09-robot-revolution-china-factory-floors.html.

[725] Shanjun Li, "谁来'智造'中国的 2025, 机器人!" [Who to Digitize China in 2025—Robots!], Minsheng Securities, May 20, 2015.

[726] "Executive Summary: World Robotics 2014 Industrial Robots and World Robotics 2014 Service Robots."

Currently, the industrial arm of the robotics industry is dominated by a few leading companies. FANUC Corporation (Japan), Yaskawa Electric Corporation (Japan), KUKA AG (Germany), and ABB Ltd. (Switzerland) are the key players, accounting for more than 70 percent of Chinese market share and virtually dominating the high-end fields such as manufacturing and welding robots.[727] While China's market share of domestic robots is rising, it is still relatively low compared to foreign robots and is mainly focused on transport and loading, which is at the low end of the industrial chain.[728] The four leading Chinese robotics companies, Siasun, GSK CNC Equipment, Effort and Estun, account for only 5 percent of the total market.[729]

The total number of professional service robots sold worldwide in 2013 rose by 4 percent, but the sales value slightly decreased by 1.9 percent to $3.57 billion. About 4 million service robots for personal and domestic use were sold in 2013 worldwide, 28 percent more than in 2012. The value of sales increased to $1.7 billion.[730] Key application areas for service robots overall are defense, agriculture, and household use.[731]

Technology Levels

The big difference in market share points out an obvious gap between Chinese firms and foreign competitors in robot and automation technology. Chinese industrial robots lag behind foreign-produced robots and automation equipment in terms of speed and precision.[732] A lack of core components technology is the main impediment to domestic robot development.[733] China is highly dependent on imports of key components, with more than 70 percent imported.[734] More specifically, 80–90 percent of domestic robots use foreign decelerators, 60–70 percent use foreign motors, and 40–50 percent use foreign controllers.[735] Japan, the United States, and Europe are the main exporters of these core components.[736] Japan's Hamer Tenneco and Nabtesco dominate the decelerator market, and the importation of these products is costly for China.[737] Increasing domestic production will help China's goals to reduce such costs as well as its dependence on foreign suppliers.

[727] "外企四大家族占据中国机器人产业 70% 以上" [Top Four Foreign Firms Occupied More Than 70 Percent of China's Industrial Robots Market], 搜狐财经 [Sohu Finance], January 19, 2015, http://business.sohu.com/20150119/n407890526.shtml.
[728] "中国机器人年销 4.5 万台世界第一: 核心部件全进口" [Sale of Robots in China Ranked No.1 but All Core Components Are Imported], 新浪军事 [Sina Military], January 16, 2015, http://mil.news.sina.com.cn/2015-01-16/1007818423.html.
[729] "Top Four Foreign Firms Occupied More Than 70 Percent of Chinese Industrial Robots."
[730] "Executive Summary: World Robotics 2014 Industrial Robots and World Robotics 2014 Service Robots."
[731] Ibid.
[732] Greg Isaccson, "Robots in China: The Bot Connection," CKGSB Knowledge, November 11, 2014, http://knowledge.ckgsb.edu.cn/2014/11/11/technology/robots-in-china-the-bot-connection/.
[733] "Automation Hampered in China by High Import Costs of Robot Parts," *Want China Times*, June 8, 2015, http://www.wantchinatimes.com/news-subclass-cnt.aspx?id=20150608000016&cid=1102.
[734] Yan Li, "我国机器人产业崛起之困" [The Dilemma of the Rise of Chinese Robot Industry], 科技日报 [*Science and Technology Daily*], September 24, 2014, http://digitalpaper.stdaily.com/http_www.kjrb.com/kjrb/html/2014-09/24/content_278588.htm?div=-1.
[735] "Sale of Robots in China Ranked No. 1."
[736] Yan Li, "The Dilemma of the Rise of Chinese Robot Industry."
[737] "Automation Hampered in China by High Import Costs of Robot Parts."

Policy Measures

China has invested heavily in technology R&D on key robotic components over the past 40 years but has not yet achieved satisfactory results. Several policies have been issued to address this issue and to boost the development of the robotics industry. Intelligent service robots were identified as a cutting-edge technology in the MLP in 2006. In the 12th Five-Year Plan on the Development of Strategic Emerging Industries, published in 2012, intelligent manufacturing equipment, including industrial robots, is listed as an area that requires special policy support.[738] A special 12th Five-Year Plan for Service Robot Technology Development was released the same year.

MIIT released its Guideline on Promoting the Development of Industrial Robots (关于推进工业机器人产业发展的指导意见) in 2013, which outlined a 2020 goal of having at least three globally competitive robot makers, eight subcontractor clusters, a 45 percent domestic market share for Chinese high-end robots, and a tripling of robot penetration to 100 per 10,000 workers.[739] Specific regional support policies are being consolidated on the back of the central government's guidelines. More than 36 cities, such as Guangzhou, Shanghai, and Dongguan, have made robots their priority development target.[740]

The Made in China 2025 plan also emphasizes the development of a high-end CNC machine and robots industry.[741] This plan is intended to upgrade the entire manufacturing sector, with "smart manufacturing" as the key focus. According to MIIT Vice Minister Miao Weiming, robots are one of the key components of this goal.[742] Liu Tao, another official from the equipment department at the MIIT, recently outlined new favorable policies being issued by the government, which "will include subsidies for companies who buy local brand robots, and a national merger and acquisition fund to help Chinese makers acquire world-advanced technologies from companies." According to Liu, the government will also "help enhance public awareness and trust in Chinese robots" as a way to promote local robot brands among Chinese users.[743]

Ten 863 Plan projects are designated to support robotics technology development in 2014 and 2015 (Table 12). The list makes it clear that China is committed to advancing key robotics components technologies as well as the development of collaborative robots.

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738 "国务院关于印发"十二五"国家战略性新兴产业发展规划的通知" [The State Council's Notice to Issue "12th Five-Year" National Strategic Emerging Industry Development Plan], July 9, 2012, http://www.gov.cn/zwgk/2012-07/20/content_2187770.htm.

739 Timothy Aeppel and Mark Magnier, "China's Hunger for Robots Marks Significant Shift," *Wall Street Journal*, July 5, 2015, http://www.wsj.com/articles/chinas-hunger-for-robots-marks-significant-shift-1436118228.

740 Shanjun Li, "Who to Digitize China in 2025—Robots!"

741 Ibid.

742 "机器人十三五规划将出 中国成最大机器人市场" [The Robot 13th Five-Year Plan Is Coming: China to Become the Biggest Market for Robots], 中商情报网 [Zhongshang Information], July 29, 2015, http://www.askci.com/news/chanye/2015/07/29/113353ilhw.shtml.

743 Tan Yingzi, "China to Give Robot Makers Subsidies and Funding," *China Daily*, September 16, 2015, http://en.people.cn/business/n/2015/0916/c90778-8950968.html.

Table 12. 863 Plan projects on robotics technology

Year	Project Name (English)	Project Name (Chinese)	Duration
2014	Application and demonstration of filling and detecting robot and automatic production line system for explosive goods	面向易爆危险品装填及检测的机器人及成套自动化生产线系统的应用示范	Unknown
2014	Application and demonstration of economical industrial robot under harsh production environment	面对恶劣生产环境下经济型工业机器人应用示范	Unknown
2015	Core components of industrial robots	工业机器人核心基础部件应用示范	3 years
2015	Key technology and system of big data-based humanoid intelligence	基于大数据的类人智能关键技术与系统	
2015	Development and application demonstration of precise robot harmonic reducer	机器人精密谐波减速器研制及应用示范	3 years
2015	Development and application demonstration of precise bearing for robot	机器人用精密轴承研制及应用示范	3 years
2015	Research and application demonstration of mobile manipulator arm key technology	移动操作机械臂核心技术研究及应用示范	3 years
2015	Heart and cerebral vessels real-time intervention robotic system	心脑血管实时介入机器人系统	3 years
2015	Spine minimally invasive surgery robotic system	脊柱微创手术机器人系统	3 years
2015	Anterior cruciate ligament fracture repair surgery robotic auxiliary system	前交叉韧带断裂修复术中机器人辅助系统	3 years

Sources: MOST, "国家高技术研究发展计划 (863 计划)、国家科技支撑计划制造领域 2014 年度备选项目征集指南" [2014 National High-Tech Research and Development Plan (863 Plan), National S&T Supporting Plan Manufacturing Alternative Projects Solicitation Guide], April 16, 2013, http://www.most.gov.cn/tztg/201304/t20130416_100885.htm; "2015 National High-Tech Research and Development Plan (863 Plan) Application Guide."

Such policy support has sparked new developments in the Chinese robotics industry. By the end of 2014, China had more than 530 robot companies, of which more than 60 are listed on the Shanghai and Shenzhen stock markets. More than 40 industrial parks have been built, and total investment in local robotics industrial parks is expected to exceed 500 billion RMB ($77.75 billion) in 2020.[744] However, industry experts also warned of the risk of creating bubbles caused in part by government intervention.[745] Currently, a majority of Chinese robot companies are small-scale manufacturers focusing on systems integration. Only a handful are engaged in robot body manufacturing.[746]

Implications for the United States

The United States is not currently a significant producer of traditional completed industrial robots for global markets, and consequently has little direct competition with Chinese firms. However, it is a major player in robotics components and related technologies, such as sensors, software, machine vision, and system integration, which are critical in the robotics supply chain.[747] US exports of industrial robots reached $494.1 million in 2013 with about half of the value coming from parts.

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[744] Shanjun Li, "Who to Digitize China in 2025—Robots!

[745] Pete Sweeney, "In China, High Demand for Robots but too Many Robot Manufacturers," Reuters, October 28, 2014, http://www.reuters.com/article/2014/10/29/us-china-robots-idUSKBN0IH28O20141029.

[746] "冷静对待机器人产业热" [Stay Calm with Robot Fever], 中国机器人网 [www.robot-china.com], August 21, 2015, http://www.robot-china.com/news/201508/21/24436.html.

[747] Author interview with Jeff Burnstein, president, Robotics Industry Association, January 26, 2016.

China is one of the top destinations for US exports of industrial robots.[748] Moreover, the United States is one of the leaders in the development of cutting-edge robotics in the form of collaborative robots. Consequently, the long-term export potential of the US robotics industry is considerable.

Besides being the largest market for industrial robots, China's robotics market is also growing faster than most other countries. As the Chinese government strives to automate and upgrade its manufacturing sector and promote wider use of robots, demand for complete robots and industrial robot parts is expected to grow even more. As noted earlier, China lags foreign competitors significantly and is highly dependent on importing key components. Domestic firms are unlikely to match market demand in the short term. US firms that have advanced robotics technology and the capacity to produce key components will benefit from the growing demand in China.

US firms can further increase their presence in China through cooperation with local firms and governments. This is a strategy that is being successfully conducted by Japanese and European robot makers. For instance, the Swiss-based robot maker ABB signed a cooperative agreement with the Guangdong Provincial Development and Reform Commission to enhance the competitiveness of Guangdong's robotics industry through the establishment of an industrial robot R&D and manufacturing base in the Zhuhai High Tech Industrial Development Zone. This initiative has steadily boosted ABB's presence in Guangdong. ABB also actively promotes and is engaged in industry-academia partnerships, which is another way to facilitate its business expansion efforts.[749]

As the Chinese industrial robot market is dominated by foreign robot makers, European and Japanese manufacturers are the biggest competitors to the United States. To combat their Japanese and European rivals, US robot manufacturers need to deploy similar strategies and expand their consumer base. In addition, cooperation with local firms and government will allow US companies to enjoy the various incentives offered by central and local governments, such as land use and tax breaks.[750]

Another opportunity for US companies lies in collaborative robots designed for direct interaction with humans during production operations.[751] As industry expert Jim Lawton notes, "what's needed and what will ensure that China . . . will reap the rewards of digitized manufacturing is a new breed of smart, collaborative robot."[752] Chinese officials clearly share the same vision, as collaborative robots have been identified as a key area in various state plans as well as a research

[748] Michael Stanton-Geddes and Dennis Fravel, "US Manufacturing Companies Are Global Leaders in Industrial Robot Consumption," USITC Executive Briefings on Trade, May 2014, http://www.usitc.gov/publications/332/ebotindustrialrobots5-14-14.pdf.

[749] Yuki Matsuda, "Challenges and Strategies for China's Industrial Robotics Market," Mizuho Industry Focus 169, March 2015, Mizuho Bank, Tokyo, http://www.mizuhobank.com/service/global/cndb/economics/msif/pdf/15-0110-AF-0103.pdf.

[750] Ibid.

[751] Tanya Anandan, "The Realm of Collaborative Robots: Empowering Us in Many Forms," June 17, 2014, http://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/The-Realm-of-Collaborative-Robots-Empowering-Us-in-Many-Forms/content_id/4854.

[752] Jim Lawton, "As China Moves from Volume to Value, So Do Robots," *IndustryWeek*, July 21, 2015, http://www.industryweek.com/robotics/china-moves-volume-value-so-do-robots.

focus in the 863 Plan. The Made in China 2025 plan will be a major force behind the expansion of the Chinese market for such robots, which is estimated to surpass $3 billion by 2020.[753]

The United States has a significant business opportunity in collaborative robots. It holds an advantage in robots with advanced vision capabilities and anticipatory artificial intelligence. Lawton points out that "[m]ost of the technology that's required to be able to build this next wave of robotics exists in the United States"[754] The National Robotics Initiative, launched by the Obama administration in 2011, has spent about $300 million in new robotics R&D that has "been very focused on robots working with humans," according to Henrik Christensen, the KUKA chair of robotics at the Georgia Institute of Technology. Several US technology giants, such as Google, Amazon, and Apple, have already begun to invest in robotics.[755] Penetration of the rapidly growing Chinese robotics market will help the development of the US robotics industry. Rethink Robotics, the leading US manufacturer of collaborative robots, is a recent beneficiary of the growing Chinese robotics market. As a result of its cooperation with the newly established "collaborative robotics application promotion industry alliance," an initiative of Tsinghua University, Hunan Cothink Robotics Tech and the Changsha Yuhua economic development zone, its Sawyer collaborative robots will be promoted in China.[756]

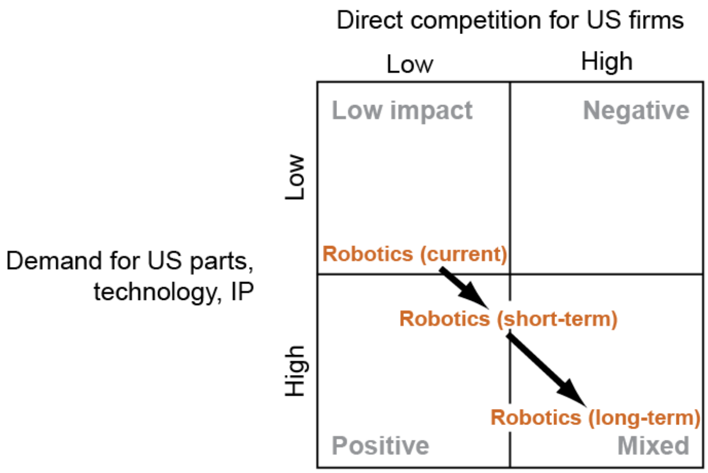
Even though the Chinese government has provided strong support to boost development of its domestic firms, the real competition for US firms currently and in the short term is with their Japanese, German, and other European counterparts. However, in the long term, as government support and investment grows, China is likely to close the gap with its foreign competitors. Furthermore, one or two of the current leading Chinese robotics firms such as Siasun, GSK CNC Equipment, Effort, Estun, or Wuhan Huazhong may emerge to become among the big four global robot makers. The Chinese companies are well-managed, forward-thinking, and profitable, and they enjoy a high degree of state subsidies and support through established robotics research institutes. While the United States may face increased competition from China, demand for US products and technology is likely to remain high as long as the United States maintains its leading position in robotics-related technology (Figure 20).[757]

Despite potential competition with Chinese robot makers, the Chinese government's drive for greater adoption of robots in its manufacturing industry may pose a threat to the US manufacturing workforce. The National Association of Manufacturers estimates that the manufacturing industry supports 17.6 million jobs in the United States. As US companies outsourced their manufacturing operations to emerging markets, especially China, in order to take advantage of lower labor costs, US manufacturing jobs steadily declined from 1996 to 2013. This trend, however, is beginning to shift because of the rapidly rising labor costs in China. [758] If Chinese manufacturers successfully

753 Ibid.
754 Andrew Zaleski, "Can the US Win the Robotics War on the Factory Floor?" CNBC, June 3, 2015, http://www.cnbc.com/2015/06/03/can-the-us-win-the-robotics-war-on-the-factory-floor.html.
755 Ibid.
756 "长沙发起成立协作机器人应用 促进产业联盟" [Changsha Initiated the Establishment of Collaborative Robots Application Promotion Industry Alliance], Xinhua News, November 25, 2015, http://www.hn.xinhuanet.com/2015-11/25/c_1117256744.htm.
757 Isaccson, "Robots in China."
758 Association for Advancing Automation, "Robots Fuel the Next Wave of US Productivity and Job Growth," October 2015, http://www.a3automate.org/docs/A3WhitePaper.pdf.

maintain or even increase their cost advantage through the adoption of robotics, the US manufacturing workforce is likely to continue to be negatively affected.

Figure 20. Outcomes of Chinese investment in advanced robotics for US firms



Nanomaterials

As an evolving technology, there is not a single agreed-upon definition of nanotechnology. The US National Nanotechnology Initiative offers the following definition:

> science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.[759]

Nanomaterials are an increasingly important product of nanotechnologies. Different forms of nanomaterials include nanotubes, graphene, nanocomposites, nanofibers, nanoparticles, and nanowires. They are coming into use in healthcare, electronics, energy, environment, and other areas.[760] With enormous prospects for technological innovation in multiple areas held by nanotechnology and nanomaterials, there is a concerted race to become the global leader in this area.

The United States is the global leader in nanotechnology, enabled by large public and private investments in R&D. While China's overall nanotechnology R&D growth is notable, it still lags in quality. Coupled with other issues within the Chinese nanomaterials industry, including low commercialization rates, lack of original innovation, and limited industry talent, US firms are unlikely to face direct competition with Chinese firms. Yet the rapidly growing market in China presents promising expansion opportunities for US firms.

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[759] "What It Is and How It Works," National Nanotechnology Initiative website, accessed January 31, 2016, http://www.nano.gov/nanotech-101/what.

[760] "Nanomaterials Level 1," European Commission Public Health website, accessed October 9, 2015, http://ec.europa.eu/health/scientific_committees/opinions_layman/nanomaterials/en/.

Market Characteristics

The 2014 global market for nanomaterials was valued at $3.4 billion and is estimated to reach $11.8 billion by 2020, with a CAGR of 23.1 percent.[761] The high growth rate driven by both increased market penetration of existing materials and development of new materials and applications.[762] While demand is expected to remain robust for top users of nanomaterials, such as the electronics and electric and healthcare industries, the fastest growing demand is expected to be in energy and construction. Some other smaller markets, such as aerospace, defense, packaging, and sports equipment also present significant opportunities for market expansion.[763]

North America was the largest market in 2014, followed by Europe, owing to significant use of nanomaterials in the medical and electronics industries.[764] The Asia Pacific region is viewed as the fastest growing market because of increasing investments in the medical and automotive industries in countries such as China and India. Key market participants include Arkema, Bayer AG, Showa Denko, DuPont, Ahlstrom, Hollingsworth & Vose, Kuraray, Finetex, Elmarco, Nanocyl SA, CNano Technology Ltd., and Hyperion Catalysis International Inc.[765]

The Chinese nanomaterials market was worth RMB 3.5 billion ($544.25 million) in 2012, according to a research report by Qianzhan Industrial Research Institute. It was expected that the market would expand to RMB 7 billion ($1.09 billion) in 2017 with an annual growth rate of more than 15 percent.[766]

Technology Levels

The United States remains the leader in nanotechnology R&D, but international competition for leadership has increased on many fronts.[767] China has been actively increasing nanotechnology investment to compete in the global market.[768] It ranked second only to the United States in in-

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761 "Global Nanomaterials Market—Segmented by Product Type, End-User Industry, and Geography—Trends and Forecasts (2015–2020)," PR Newswire, September 21, 2015, http://www.prnewswire.com/news-releases/global-nanomaterials-market---segmented-by-product-type-end-user-industry-and-geography---trends-and-forecasts-2015-2020-300146744.html.

762 The Freedonia Group, promotional brochure for *World Nanomaterials Industry Study with Forecasts for 2016 & 2021*, *Study #2871, May 2012,* 5, http://www.freedoniagroup.com/brochure/28xx/2871smwe.pdf.

763 Ibid.

764 "Global Nanomaterials Market—Segmented by Product Type, End-User Industry, and Geography."

765 Ibid.

766 Qian Zhu, "纳米材料应用广 行业发展前景诱人" [Wild Application of Nanomaterials; Attractive Industry Prospects], 前瞻产业研究院 [Qianzhan Industrial Research Institute], December 3, 2013, http://www.qianzhan.com/analyst/detail/220/131203-8978bb65.html.

767 United States Government Accountability Office, "Nanomanufacturing: Emergence and Implications for US Competitiveness, the Environment, and Human Health," January 2014, GAO-14-181SP, http://www.gao.gov/assets/670/660591.pdf.

768 Ministry of Science and Technology, "中国纳米材料产业现状调研报告 (2001)" [Chinese Nanomaterial Industry Research Report (2001)], July 2001, 13–16, http://wenku.baidu.com/link?url=rR_6-Bgkfo0UgWlHLp8lNWl-wBCup4jtyF9kVpwq1fsQyGnkrXrEhQcg-O5oYD_ETVse2gPVWk3OJOAL-nDtDpBC2UMVC_fidv9AjpqxLPMPC.

vestment in 2014 and has emerged as one of the global leaders in the development of basic nanotechnology.[769] As for the number of publications, citations, and patents in nanotechnology, China has held first place since 2007.[770] However, the most widely cited publications are still authored by researchers based in the United States and Europe.[771] Furthermore, Chinese scholars believe that Chinese investment in nanotechnology research is dispersed and that much of the research lacks originality.[772]

China has become a leader in the production of some nano-related industrial products, for example, nano filters for air conditioners; nanomaterial textiles and clothing that have enhanced antimicrobial properties; nano coatings and plastics for refrigerators; and anti-corrosive nano paints used in oil tanks.[773] However, the Chinese nanomaterial industry suffers from poor industrialization and low commercialization of research output. Private enterprises account for only five percent of China's nanotech R&D capability, while universities and the CAS account for more than 90 percent.[774] Most nano products produced by Chinese firms are of a low technological standard, and no Chinese domestic nanomaterials company has reached a leading position in the global industry. Current domestic industrial leaders are Beijing Shouchuang Nanotechnology Company, Shenzhen Nanotech Port Company, and Tianjin Ruikai Technology Development Company.

The primary goal of the industry is to further develop the domestic market and expand market share.[775] However, this is hampered by a lack of capital. Around 90 percent of nanomaterials companies have less than RMB 50 million ($7.8 million) in registered capital, which indicates that a majority are still at an early stage of development. It is very common that research plans end halfway or cannot be commercialized due to insufficient funds.[776] The gap in financial support is so great that investment from the government alone cannot fill it. In addition, the industry lacks strong support from related industries and an insufficient supply of industry talent.[777] Consequently, even with strong government support, US firms are still likely to face relatively limited direct competition from Chinese firms.

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[769] Anne Clunan and Kirsten Rodine-Hardy, "Nanotechnology in a Globalized World: Strategic Assessments of an Emerging Technology," PASCC Report 2014-006, 54, http://calhoun.nps.edu/bitstream/handle/10945/43101/2014%20006%20Nanotechnology%20Strategic%20Assessments.pdf?sequence=4&isAllowed=y.

[770] Zhao Zhuqing, "我国纳米科技领域论文数和专利量世界第一" [China Holds First Place on the Number of Publications and Patents in the Nanotechnology Area], *People's Daily,* September 6, 2015, http://scitech.people.com.cn/n/2015/0906/c1007-27547157.html.

[771] Clunan and Rodine-Hardy, "Nanotechnology in a Globalized World," 67.

[772] Zhao Zhuqing, "China Holds First Place on the Number of Publications and Patents."

[773] "Nanotechnology in a Globalized World: Strategic Assessments of an Emerging Technology," 54.

[774] "Chinese Nanomaterial Industry Research Report (2001)."

[775] "我国纳米材料行业发展现状分析" [Analysis of Chinese Nanomaterials Industry], Baidu.com, October 21, 2014, http://jingyan.baidu.com/article/d5a880eb96ae6613f147ccb1.html.

[776] Ping Zhaoxia, "北京纳米材料产业发展分析" [Nanomaterials Industry in Beijing], 新材料产业 [*Advanced Materials Industry*] 1 (2014): 20.

[777] Gong Weimi, Ren Hongxuan, and Wan Fei, "世界纳米科技企业现状与我国纳米企业发展需求分析" [State of World's Nanotechnology Enterprises and Analysis on the Development Needs of China's Nano Companies], 新材料产业 [*Advanced Materials Industry*] 8 (2014): 31.

Policy Measures

Although China still lags behind the United States in research quality and commercialization of research, it is determined to catch up and "leapfrog" the development cycle.[778] Since the mid-1980s, the National Natural Science Foundation of China and CAS have supported scanning tunneling microscope−related research, and gradually wider research topics at the nanoscale level. Both the 863 and 973 plans set nanomaterials R&D as a priority funding area.[779] The National Steering Committee for Nanoscience and Nanotechnology (NSCNN, 国家纳米科学技术指导协调委员会) was established in 2000 to coordinate and streamline all national research activities.[780] In the following year, the first national initiative on nanotechnology, the National Nanotechnology Development Strategy (2001−2010) (国家纳米科技发展纲要), was issued, calling for technological breakthroughs in "nanomaterials production and fabrication, construction and integration of nanoscale devices, nanofabrication technologies, nano-scale structural analysis and performance testing techniques, and indigenous innovation in nanomaterials production devices."[781]

More importantly, nanotechnology development is identified as a megaproject under the MLP. Nanomaterials and nano device R&D is one of its foci. Between 2006 and 2008, the MLP funded 29 nanotechnology projects at 22 universities and research institutes across the country, totaling $38.2 million. [782] Nanomaterials technology is also a focus in the development of new materials, identified as one of the nation's SEIs. In addition to support for R&D, the SEI strategy also encourages domestic enterprises to go abroad, acquire foreign firms, merge and reorganize to increase competitiveness, and expand global markets with high-value-added material products. China supports imports of new material products and technology. Foreign enterprises that produce high-value-added products are encouraged to invest and establish factories in China.[783]

Recent policies have focused on the application of nanotechnology and the role of original innovation. The most relevant initiative is the 12th Five-Year Special Plan for Major National Scientific Research on Nano Research (纳米研究国家重大科学研究计划"十二五"专项规划), issued by MOST in 2012.[784] The main goal of this plan is to make original breakthroughs in nanomaterials and further expand its application in the information technology, biopharmaceutical, energy, envi-

[778] Clunan and Rodine-Hardy, "Nanotechnology in a Globalized World," 54.
[779] Ibid., 50.
[780] Darryl S. L. Jarvis and Noah Richmond, "Regulation and Governance of Nanotechnology in China: Regulatory Challenges and Effectiveness," *European Journal of Law and Technology* 3 (2011): 3, http://ejlt.org/article/view/94.
[781] Ministry of Science and Technology, "科学技术部、国家发展计划委员会、教育部、中国科学院、国家自然科学基金委员会关于印发《国家纳米科技发展纲要(2001–2010)》的通知" [Notice of Five Ministries on Issuing the "National Nanotechnology Development Plan (2001–2010)"], July 6, 2001, http://www.most.gov.cn/fggw/zfwj/zfwj2001/200512/t20051214_55037.htm.
[782] Jarvis and Richmond, "Regulation and Governance of Nanotechnology in China."
[783] Ministry of Commerce, "关于促进战略性新兴产业国际化发展的指导意见" [Guidance on the Promotion of the International Development of Strategic Emerging Industry], November 18, 2011, http://www.mofcom.gov.cn/aarticle/i/ck/201111/20111107836186.html.
[784] Ministry of Science and Technology, "科技部关于印发纳米研究等 6 个国家重大科学研究计划"十二五"专项规划的通知" [Notice of MOST on Issuing Six Special Plans for National Major Scientific Research Including Nanotechnology], June 21, 2012, http://www.most.gov.cn/tztg/201206/t20120621_95215.htm.

ronment, and manufacturing areas. The role of the NSCNN and industrial bases have been emphasized as a measure to achieve its goal. [785] Nanomaterials are also emphasized in the Made in China 2025 plan as a strategic frontier material. As for R&D activities, a total of 22 projects under the 863 and 973 plans are focused on nanotechnology and nanomaterials in 2014 and 2015 (Table 13). Even though nanotechnology applications are emphasized in the various strategies, the majority of research projects are still focused on basic research.

Implications for the United States

Currently, the increased emphasis on the nanomaterial industry through China's state S&T plans is likely to have a low impact on the United States. As discussed earlier, the United States holds a leading position in technology capabilities and is unlikely to have direct competition with China. Additionally, the US companies have a large presence globally, and Chinese demand for US products and technology is not very high. [786]

The short-term impact on the United States will likely be positive. With active government participation and heavy investment in R&D by major players, the Chinese nanomaterial market will continue to grow rapidly, increasing its demand for US products and technology. Competition from local Chinese firms will likely remain low as issues hampering the development of this industry will not be solved anytime soon. As already noted, the commercialization of nanotechnology in China has been slow compared to advanced countries such as the United States, but despite nearly three decades, state-directed plans have not addressed it effectively. The MLP listed nanotechnology under the basic science plan section rather than the engineering section.[787] More resources have been dedicated to basic research than to applications, as indicated in recent projects under the 863 and 973 plans.

In addition to a low ratio of research achievement transfers, insufficient industrialization plagues the Chinese nanomaterial industry. Since universities and research institutes in China lack the capability and capital to commercialize their research findings, local governments play a critical role in providing support. Local governments, however, are subject to economic and political pressures for high increases in GDP, making them eager for earlier returns on investment. As a result, the high risk and long conversion cycles associated with nanotechnology are ignored, and resources and government funding may end up invested in low-end projects with firms that may not have adequate R&D capability. This impatience has contributed to the low level of industrialization of nanotechnologies in China.[788]

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[785] "纳米研究国家重大科学研究计划'十二五'专项规划解读" [Explanation of the 12th Five-Year Plan for National Nanotechnology Major Scientific Research], Xinhua Net, July 16, 2012, http://news.xinhuanet.com/politics/2012-07/16/c_123416368.htm.

[786] Lucintel, "Global Nanomaterials Opportunity and Emerging Trends," PowerPoint presentation, March 2011, http://www.lucintel.com/lucintelbrief/globalnanomaterialsopportunity-final.pdf.

[787] Clunan and Rodine-Hardy, "Nanotechnology in a Globalized World," 56.

[788] Camilo Fautz, Torsten Fleischer, Ying Ma, Miao Liao, and Amit Kumar, "Discourses on Nanotechnology in Europe, China, and India," in *Science and Technology Governance and Ethics*, ed. Miltos Ladikas et al. (Switzerland: Springer International Publishing AG Switzerland, 2015), 130.

Table 13. 863 and 973 plan projects on nanomaterials

Year	Project Name (English)	Project Name (Chinese)	Duration
863 Plan			
2014	High precision silicon pressure sensor and system	高精度硅压力传感器及系统	Unknown
2014	High-end micro-nano component design for manufacturing technology	高端微纳器件可制造性设计技术	Unknown
2014	Design and manufacturing of arrayed micro-nano sensor	阵列化微纳传感器设计与制造技术	Unknown
2014	Integration of three dimensional heterogeneous MEMS	微纳系统三维异质集成化技术	Unknown
2014	Design and manufacturing of AIN-MEMS	硅基氮化铝微纳系统（AIN-MEMS）的设计与制造技术	Unknown
2014	Key technology and equipment of femtosecond laser pulse sequence micro-nanofabrication	飞秒激光脉冲序列微纳加工关键工艺与装备	Unknown
2015	Ultra-precision manufacturing technology and equipment of nano-impressing roller	微纳米压印辊筒超精密制造技术及装备	3 years
2015	Manufacturing equipment detection used multi-functional micro-nano sensor and system	制造装备检测用多功能微纳传感器及系统	3 years
973 Plan			
2014	Research on key scientific issues of liquid phase laser cladding and in the preparation of a number of optoelectronic nanomaterials	液相激光熔蚀及在若干光电纳米材料制备中的关键科学问题研究	5 years
2014	Nanocomposites for environmental safety in confined compartments	密闭舱室环境安全保障纳米复合材料	5 years
2014	Study on the water environment process, biological effect and regulation of the typical artificial nanomaterials	典型人工纳米材料的水环境过程、生物效应及其调控研究	5 years
2014	Functional assembly of nano-intercalation materials and effective utilization of magnesium resources in Saline Lake	纳米插层材料功能组装与盐湖镁资源有效利用	5 years
2014	Basic research on improving the effectiveness and safety of pesticides by using nanomaterials and technology	利用纳米材料与技术提高农药有效性与安全性的基础研究	5 years
2014	Design and regulation of efficient energy conversion and storage nanomaterials of secondary lithium-air battery	二次锂空气电池高效能量转换与储存纳米材料的设计与调控	5 years
2014	Regulation of organic nano-aggregate interface molecular orientation and application of optoelectronic device	有机纳米聚集体界面分子取向调控及光电器件应用基础研究	5 years

Table 13. 863 and 973 plan projects on nanomaterials (continued)

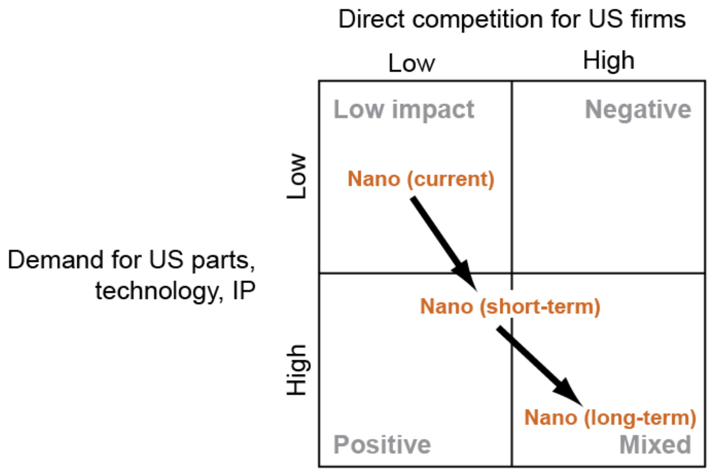
Year	Project Name (English)	Project Name (Chinese)	Duration
2014	Study on high efficiency metal nano catalyst for preparation of high quality liquid fuel by syngas conversion	合成气转化制备优质液体燃料的高效金属纳米催化剂研究	5 years
2015	Basic research on the mechanism and technology of nanometer resolution optical imaging	纳米分辨快速光学成像机理与技术的基础研究	5 years
2015	Basic research on single photon detection of superconducting nanowires	超导纳米线单光子检测应用基础研究	5 years
2015	Basic research on the application of functional nanomaterials in the removal of pollutants in groundwater	功能纳米材料在地下水体优控污染物去除中的应用基础研究	5 years
2015	New nano-plasmonic components for optical information processing	面向光信息处理功能的新型纳米等离激元器件	5 years
2015	Key scientific problems in flexible energy storage nanomaterials	柔性能源存储纳米材料中的关键科学问题	5 years
2015	New nano information devices and integration method based on two dimensional layered materials	基于二维层状材料的新型纳米信息器件与集成	5 years

Sources: Ministry of Science and Technology, "国家高技术研究发展计划（863 计划）、国家科技支撑计划制造领域 2014 年度备选项目征集指南" [2014 National High-Tech Research and Development Plan (863 Plan), National S&T Supporting Plan Manufacturing Alternative Projects Solicitation Guide], April 16, 2013, http://www.most.gov.cn/tztg/201304/t20130416_100885.htm; Ministry of Science and Technology, "国家高技术研究发展计划（863 计划） 2015 年度项目申报指南" [2015 National High-Tech Research and Development Plan (863 Plan) Application Guide], (Beijing, China 2014), http://www.most.gov.cn/tztg/201402/W020140221598529377115.doc; "2014 年国家重点基础研究发展计划(973 计划)项目专项经费预算拟安排情况汇总表" [2014 National Basic Research and Development Plan (973 Plan) Summary of Special Budget], Baidu.com, November 12, 2013, http://wenku.baidu.com/view/8d388ae95fbfc77da369b100.html; Ministry of Science and Technology, "关于国家重点基础研究发展计划（973 计划）2015 年新立项项目预算安排（前两年）初步方案的公示," [Announcement of 2015 Budgetary Arrangements for New National Basic Research and Development Plan Projects (First Two Years)], December 10, 2014, http://www.most.gov.cn/tztg/201412/t20141210_116929.htm.

With continuing government support and a solid foundation in academic research, the Chinese nanomaterial industry will likely eventually grow and directly compete with US firms in the Chinese market, making the long-term impact on the United States uncertain (Figure 21). First, the United States and China have focused on different areas in nanotechnology development. The United States has made heavy investments in the life sciences, whereas China is strong in materials science. It is unclear which area is likely to embrace new, disruptive materials that might have revolutionary effects on other industries. [789] Second, the United States may not benefit from the high demand of China's market if China exercises intervention and introduces trade barriers.

[789] Clunan and Rodine-Hardy, "Nanotechnology in a Globalized World," 76.

Figure 21. Outcomes of Chinese investment in nanomaterials for US firms



Electric Vehicles

The modern electric vehicle (EV) industry consists of three types of vehicles: plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV), and fuel cell electric vehicles (FCEV). PHEVs combine both internal combustion engines and a high-capacity rechargeable battery. BEVs are powered solely by energy stored in an on-board battery. FCEVs run on a fuel cell that generates electricity by converting chemical energy, such as hydrogen, into electrical energy.

Both the United States and China have struggled to foster significant demand in EVs, despite the provision of government subsidies for consumers in both countries. EVs are a prominent industry focus in China's state plans, which set challenging goals for the industry in both technology and demand. China's EV industry so far has struggled with severe local protectionism that has impeded the growth of its domestic industry. The low levels of EV technology and adoption in China, however, have not opened up many opportunities for US automakers in the Chinese market, which face the same barriers of protectionism, low demand, and lack of widespread charging infrastructure as Chinese firms face. At home, US EV makers also face challenges that make it difficult to grow.

Market Characteristics

In 2014, the total global market for EV reached 740,000 vehicles for a year-on-year growth rate of 76 percent. The US market during this period grew 69 percent, to reach 290,000 EVs, approximately one-third of total EV demand in the world. While significantly behind the United States in number of EVs and certainly in per capita EV ownership, Chinese ownership grew rapidly in 2014, with a growth rate of 120 percent and 54,000 new EV registrations, bringing the total number of EVs in China to 100,000.

Current global growth is led by a few car models: the Nissan Leaf, Chevrolet Volt, Toyota Prius PHEV, Tesla Model S, and Mitsubishi Outlander PHEV.[790] Viewing market shares by country of manufacture, in 2012, the United States had the largest market share (70 percent) of the worldwide PHEV market, due to the predominance of the Chevrolet Volt. It is followed by Japan (12 percent)

[790] James Ayre, "Electric Car Demand Growing, Global Market Hits 740,000 Units," CleanTechnica, March 28, 2015, http://cleantechnica.com/2015/03/28/ev-demand-growing-global-market-hits-740000-units/.

and the Netherlands (8 percent). In the BEV market, Japan had the largest market share (28 percent) from sales of the Nissan Leaf, followed by the United States (26 percent), and China (16 percent). China's relatively high share is a result of electric taxi use in Shenzhen and Hangzhou. Leading Chinese manufacturers include BYD, Kandi, Chery, and Zotye. Among these companies, only Chery is state-owned but reportedly still "looks, feels, and has the DNA of a private company."[791] BYD's 2014 sales reached almost 21,000 EVs to account for 28 percent of the Chinese market. Kandi's market share is around 14 percent.[792]

In the global BEV passenger car market, six models have a market share of 85 percent—the Chery QQ3EV, Zotye E20, BAIC E150 EV, BYD E6, JAC iEV4, and Zotye Cloud 100. Perhaps most notable, however, is the BYD Qin in the PHEV passenger car market. As of September 2015, it was the top-selling new energy vehicle in 2015, selling 41,045 units year-to-date. Late reports in 2015 indicated that BYD Qin sales may surpass sales of any other EV on the market and even beat out US electric car manufacturer Tesla, which had sold 33,000 cars at the end of the third quarter in 2015.[793]

As the Chinese EV market develops, more automobile companies want to compete. For example, Tesla signed an agreement with China Unicom, China's second-largest mobile communications operator, to build EV charging infrastructure units targeted at Chinese elite consumers. In August 2014, they decided to build a network of electric vehicle charging facilities at 400 Unicom stores in 120 cities, including "superchargers" in 20 Chinese cities, to offer free charges for Tesla vehicles.[794]

Other automotive companies are following suit to keep their competitive advantage in the EV market. For example, Chinese company Wanxiang Group acquired the US extended range electric sports car maker Fisker Automotive for $149.2 million in 2014.[795] The company plans to revive production of sports car by building a production plant in Moreno Valley, California, creating about 150 jobs. Before its acquisition, Fisker cars were produced in Finland.[796]

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[791] Geoff Dyer and Richard McGregor, "China's Champions: Why State Ownership Is No Longer Proving a Dead Hand," *Financial Times*, March 16, 2008, http://www.ft.com/intl/cms/s/0/979f69c8-f35b-11dc-b6bc-0000779fd2ac.html.

[792] "China Electric Vehicle Industry 2015 Analysis in New Research Report at RnRMarketRessearch.com," PRNewswire, April 14, 2015, http://www.prnewswire.com/news-releases/chinese-electric-vehicle-industry-2015-analysis-in-new-research-report-at-rnrmarketresearchcom-499639721.html.

[793] "BYD Qin Could Beat Out Tesla," *Clapway*, November 4, 2015, http://clapway.com/2015/11/04/byd-qin-could-beat-out-tesla123/.

[794] David Tyfield, "Tesla-Unicom Deal Ignites New Possibilities in China's EV Market," ChinaDialogue, October 23, 2014, https://www.chinadialogue.net/article/show/single/en/7418-Tesla-Unicom-deal-ignites-new-possibilities-in-China-s-EV-market.

[795] Alfred Tian, "回顾 2014|国际车市: 全产业链下反思电动车" [Looking Back on 2014 International Auto Industry: Entire Industry Chain Reflects on EVs], 财新博客 [Caixin Blog], January 2, 2015, http://tianyongqiu.blog.caixin.com/archives/81769.

[796] Yang Jian, "China's Wanxiang Plans to Build Fisker Karma in S. Calif.," *Automotive News*, June 21, 2015, http://www.autonews.com/article/20150621/OEM05/150629999/chinas-wanxiang-plans-to-build-fisker-karma-in-s.-calif; "Fisker Electric Car: Production Resuming? What's New?" *EV Obsession*, June 28, 2015, http://evobsession.com/fisker-electric-car-whats-new/.

Technology Levels

From the early 1990s to the present, China has invested more than RMB 37 billion ($5.75 billion) in government funds for EV. This includes RMB 8 billion ($1.24 billion) for R&D grants to original equipment manufacturers (OEMs), suppliers, and research institutes, and RMB 11 billion ($1.24 billion) to SOEs for charging infrastructure investment.[797] China had a significant rise in EV R&D in 2012, with investment equaling almost 50 percent of total spending from other countries. Despite this investment, however, from 2010 to 2014, China's global ranking in EV ecosystem development, a composite score tracking supply, demand, and enablers such as policy and regulation, fell from 3rd to 6th.[798]

Short battery life and low numbers of charging stations have limited the development and promotion of domestic BEV technology and adoption. In PHEV, China's technology gap is significant.[799] Almost all vehicle battery manufacturing equipment in China is imported.[800] This has resulted in Chinese companies having high costs and low competitiveness in the EV battery field, and has also created barriers to Chinese R&D on battery technology.[801]

China has so far missed its initial state targets for battery technology development. According to the 2012–2020 Energy Saving and New Energy Automotive Industry Development Plan, China aimed to increase battery energy density to 150 watt-hours per kilogram (Wh/kg) by 2015 and 300 Wh/kg by 2020. By early 2015, however, it had only reached 90Wh/kg, or 60 percent of its goal.[802]

China has also missed its targets for construction of charging stations by a huge margin. Only 636 charging stations (32 percent of the 2015 target) and 27,000 charging poles (7 percent of the 2015 target) were installed by early 2015. The only area in which China exceeded its target outlined in the Energy Saving and New Energy Automotive Industry Development Plan is in number of patents for core EV technology. The target was 3,000 patents, and 4,928 patents were granted.[803]

Safety is also a primary concern of Chinese EV and battery production. In April 2015, an electric bus produced by Shenzhen Wuzhoulong Motors Group combusted and caught fire due to a battery explosion while charging. Many Chinese manufacturers still produce lithium-ion batteries using manual or only partially automated processes, which fail to secure the batteries' safety, stability

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[797] Paul Gao et al., "Supercharging the Development of Electric Vehicles in China," McKinsey & Company, April 2015, 7–8, http://www.mckinseychina.com/wp-content/uploads/2015/04/McKinsey-China_Electric-Vehicle-Report_April-2015-EN.pdf?bd0bde.

[798] Ibid.

[799] Xu Yue, Wu Jun, Li Jinfeng, and Fang Wenyu, "国内电动汽车遭遇地方保护 电池技术无突破" [Domestic EV Encountered Local Protectionism and Made No Breakthroughs on Battery Technology], 中国经济网 [China Economy Network], May 27, 2014, http://www.ce.cn/cysc/ny/gdxw/201405/27/t20140527_2877002.shtml.

[800] Huang Yuanping, "孟光: 中外电动车差距主要在电池技术" [Meng Guang: The Major Gap between China and Foreign Countries on EV Is Battery Technology], 搜狐汽车 [Sohu Automotive], September 29, 2010, http://auto.sohu.com/20100929/n275336878.shtml.

[801] Luo Bing, "电池等关键技术落后 上市电动车质量水平差距大" [China Is Behind on Key Battery Technology and Electric Vehicles in the Market Vary in Quality], 中国质量报 [*China Quality Journal*], November 12, 2013, http://www.cqn.com.cn/news/zgzlb/diliu/797623.html.

[802] Gao et al., "Supercharging the Development of Electric Vehicles in China."

[803] Ibid.

and consistency. Additionally, falling profits and accumulated losses are making it difficult for Chinese manufacturers to invest in R&D to ensure battery safety.[804]

The US EV industry, while experiencing steady development of EV technology over recent years, also has not made major technological breakthroughs. Many EV experts believe that the US EV industry is at a "stalled stage" resulting from a lack of a market in North America—or anywhere else in the world—due to high prices.[805] US spending on EV R&D reached a peak in 2009.[806] Interviews with EV experts reveal four primary obstacles to continued progress in the United States—technology cost, infrastructure, government policy, and intellectual property. Some US experts familiar with China's industry do not believe that Chinese companies are necessarily behind on technology, and that the future of US and China EV competition will depend on who is able to push the technology forward and package and market it in the most effective way.[807]

Policy Measures

A mixture of financial incentives for consumers at the national and local levels and non-financial incentives contribute to rising market penetration in many countries. In California, the largest vehicle market in the United States, policymakers hope that policies such as consumer subsidies on zero emission vehicles and waived fees for zero emission vehicles in high-occupancy toll lanes will boost the number of zero emission vehicles on California roads to 1.5 million by 2025. By September 2014, California's cumulative sales of plug-in vehicles were more than 100,000, accounting for more than 40 percent of the US market.[808] At the national level, the US government provides tax credits of up to $7,500 for vehicles based on battery capacity, and 30 percent of the cost, not to exceed $30,000, for commercial EV supply equipment installation. Additionally, there is a tax credit of up to $1,000 for consumers who purchase qualified residential EV supply equipment.[809]

China offers similar subsidies and incentives for EV consumers. Financial subsidies on new energy vehicles depend on both the type of EV and range per charge (see Table 14). For the best-selling BYD Qin, that means that its average RMB 200,000 ($31,100) price tag would be reduced in 2015 to about RMB 128,620 ($20,000) when both national and local subsidies are accounted for.[810] Some Chinese firms, however, have complained that China's subsidies have phase-out deadlines

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[804] Ma Xiaohui, "电池缺陷是纯电动车的最大隐患" [Defective Batteries Are the Biggest Problem of BEV], 中国经济网 [China Economy website], April 29, 2015, http://finance.ce.cn/rolling/201504/29/t20150429_5243242.shtml.

[805] Author interviews with twelve US EV experts, located in universities, industry, national laboratories, and non-profit think tanks, May–June 2014.

[806] Ma Xiaohui, "Defective Batteries Are the Biggest Problem of BEV."

[807] Author interviews with twelve US EV experts.

[808] Morgan Lee, "CA has 100K Plug-in Cars, and Counting," *San Diego Union Tribune*, September 8, 2014, http://www.sandiegouniontribune.com/news/2014/sep/08/california-plugin-car-milestone/.

[809] Tonia Buell, "Washington State Electric Vehicle Action Plan 2015–2020," Washington State Department of Transportation, February 2015, http://www.wsdot.wa.gov/NR/rdonlyres/28559EF4-CD9D-4CFA-9886-105A30FD58C4/0/WAEVActionPlan2014.pdf, 19.

[810] David Fickling, "Tesla's Chic Is No Match for BYD's China Profits: David Fickling," *Bloomberg Business*, October 1, 2015, http://www.bloomberg.com/news/articles/2015-10-02/tesla-s-chic-is-no-match-for-byd-s-china-profits-david-fickling.

that make it difficult to predict market demand and forecast business plans beyond the subsidy expiration date.[811]

Many additional incentives are in place, but these often vary by location. One current nationwide incentive in place through December 2017 is an exemption from China's new energy vehicle purchase tax for new EV consumers.[812] Locally, in Beijing registration fees are waived for EVs.[813] Some cities, including Beijing, Shanghai, and Nanjing, provide subsidies of 15−30 percent for the construction of public service infrastructure and private infrastructure in public areas. Xian provides financial subsidies specifically for personal-use charge facility installation and charging fees to individuals who buy new energy vehicles. In some cities, including Wuhan, Xian, and Nanchang, new energy vehicles are not restricted from driving during traffic control days.[814]

Table 14. Financial subsidies on new energy vehicles in China

	Range per charge	Year	Subsidy
BEV			
	80–150 km	2013	RMB 35,000 ($5,443)
		2014	RMB 33,250 ($5,170)
		2015	RMB 31,500 ($4,898)
	150–250 km	2013	RMB 50,000 ($7,775)
		2014	RMB 47,500 ($7,386)
		2015	RMB 45,000 ($6,998)
	>250 km	2013	RMB 60,000 ($9,330)
		2014	RMB 57,000 ($8,864)
		2015	RMB 54,000 ($8,397)
PHEV			
		2013	RMB 31,500 ($4,898)
		2014	RMB 33,250 ($5,170)
		2015	RMB 35,000 ($5,443)
FCEV			
		2014	RMB 180,000 ($27,990)
		2013	RMB 190,000 ($29,545)
		2015	RMB 200,000 ($31,100)

Source: Liu Ying, "李岱昕：中国电动汽车产业政策梳理" [Li Daixin: Putting in Order China's Electric Vehicle Industry Policies], 中国网新闻中心 [China Net News Center], November 20, 2014, http://news.china.com.cn/txt/2014-11/20/content_34107902_3.htm.

[811] Xu Yue et al., "Domestic EV Encountered Local Protectionism."
[812] Ibid.
[813] Kevin Holden, "Electric Vehicles in China: An Industry Is Born," TU-Automotive, August 1, 2013, http://analysis.tu-auto.com/telematics-evs/electric-vehicles-china-industry-born.
[814] Ibid.

The bureaucratic structure of China's EV subsidies differs strongly from the United States and has led to a fragmented Chinese market characterized by severe local protectionism. These problems are compounded by the large number of national policies related to EV development. As of October 2014, China had issued more than 20 policies via the State Council, NDRC, MIIT, and MOST specifically to encourage the development of the new energy automobile industry (Table 15). The policies include production access, financial subsidies, tax credits, and technology innovation.[815]

On the subsidy front, as early as 2010, the central government had issued a document specifically outlining subsidies of RMB 60,000 ($9,330) to private purchases of EVs. Beijing, Shanghai, Changchun, Shenzhen, Hangzhou, and Hefei were pilot cities, requiring the local governments to provide additional financial support on the new energy vehicles and charging infrastructure.[816] To ensure subsidies were paid correctly, cities established directories for local new energy vehicles, with only those enterprises contained in the directory able to receive subsidies from the local government. This led to cities primarily including local companies in their directories. This complex double subsidy system contributed to the fragmentation of China's EV market.[817] In 2013, most cities were matching national government subsidies up to 50−60 percent of the vehicle sales price.[818]

Table 15. Selected significant policies in China's EV industry

Year	Policy
2009	Work Notice on Energy Reduction and New Energy Vehicles Demonstration Pilot 关于开展节能与新能源汽车示范推广试点工作的通知
2010	Notice on Development of New Energy Vehicles Subsidy Pilot 关于开展私人购买新能源汽车补贴试点的通知
2011	Work Notice on Continuing Promotion of Energy Reduction and New Energy Vehicles Demonstration Pilot 关于进一步做好节能与新能源汽车示范推广试点工作的通知
2013	Work Notice on Continuing Promotion of New Energy Vehicles Application and Demonstration 关于继续开展新能源汽车推广应用工作的通知
2014	Work Notice on One More Step of Promotion of New Energy Vehicles Application and Demonstration 关于进一步做好新能源汽车推广应用工作的通知
2014	Office of the State Council Guiding Opinions on Accelerating the Promotion of New Energy Vehicles 国务院办公厅关于加快新能源汽车推广应用的指导意见

Source: Liu Ying, "李岱昕：中国电动汽车产业政策梳理" [Li Daixin: Putting in Order China's Electric Vehicle Industry Policies], 中国网新闻中心 [China Net News Center], November 20, 2014, http://news.china.com.cn/txt/2014-11/20/content_34107902_3.htm.

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815 Liu Ying, "李岱昕: 中国电动汽车产业政策梳理" [Li Daixin: Putting in Order China's Electric Vehicle Industry Policies], 中国网新闻中心 [China Net News Center], November 20, 2014, http://news.china.com.cn/txt/2014-11/20/content_34107902_3.htm.
816 "什么在毁掉电动汽车?" [What Is Destroying the EV?], 中国经营网 [*China Business Network*], February 10, 2014, http://www.cb.com.cn/index.php?m=content&c=index&a=show&catid=26&id=1036569&all.
817 Ibid.
818 Holden, "Electric Vehicles in China: An Industry Is Born."

Data shows that EVs in China find it difficult to enter 70 percent of local markets due to protectionist barriers.[819] Some cities reportedly require that battery and other power components be purchased locally.[820] Other local governments have set up restrictions on licenses for EVs. An official from the Beijing Science and Technology Commission stated that many places require EV enterprises to have a local production qualification or that they source parts from a certain number of local suppliers. Many cities have hidden restrictions to deny entry to foreign enterprises. For example, Beijing's policy requires that EV enterprises must have their own vehicle plant in Beijing in order to enter the market.[821]

A unique approach in China's public promotion of EVs has been to encourage adoption in areas such as public transportation, rentals, logistics, businesses, and sanitation vehicles. In Changsha, Shaoguan, and Xian, pilot plans promote the use of electric buses and taxis.[822] This artificially inflates the sense that China has a sizeable market for EVs. According to a Chinese auto engineering executive, in 25 pilot cities that have placed 39,000 new energy vehicles on the road, 80 percent are in public service sectors, such as buses or taxis. This is driven by government-mandated procurement, causing many of the agencies forced to add the EVs to their inventory to "bite the bullet" and operate at a loss.[823] In September 2015, the State Council issued new guidelines that at least 30 percent of new car and bus purchases for government-funded organizations should be new-energy vehicles. Local governments that fail to meet this new guideline will have their subsidies on fuel and operating expenses reduced.[824]

A brief description of 863 plan funding for EVs and infrastructure and grid allocations is included in the energy section earlier in the report (pages 105−106).

Implications for the United States

China's national and local policies on EVs create strong barriers for foreign companies seeking to enter the Chinese market. Tesla is currently the only US EV maker that has entered the Chinese market, but it has done so with great difficulty and mixed results. Foreign companies such as Tesla are not eligible for the subsidies granted to the purchase of domestically-produced EVs. In the coming years, it is expected that local governments will gradually increase subsidies to local car enterprises, creating even larger barriers for foreign EV companies.[825] Furthermore, local protectionism imposes additional requirements on EV makers. Due to the differing policies implemented by cities, it currently would be nearly impossible for a foreign company to try to accommodate the requirements for each locality. Chinese domestic companies are facing the same challenges.

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819 "地方保护不除 新能源汽车推广难以大步前行" [New Energy Vehicles Difficult to Move Forward Without Eliminating Local Protectionism], *人民网* [*People.cn*], January 8, 2015, http://auto.people.com.cn/n/2015/0108/c1005-26347213.html.
820 Xu Yue et al., "Domestic EV Encountered Local Protectionism."
821 "What Is Destroying the EV?"
822 Holden, "Electric Vehicles in China: An Industry Is Born."
823 Xu Yue et al., "Domestic EV Encountered Local Protectionism."
824 Hao Yan, "New-Energy Vehicles to Get Renewed Push," September 30, 2015, http://english.gov.cn/news/top_news/2015/09/30/content_281475201428902.htm.
825 Huang Nan, "国外电动车能否冲出中国'雾霾'?" [Can Foreign EVs Escape China's 'Haze'?], 腾讯财经 [*Tencent Finance*], February 26, 2014, http://finance.qq.com/original/caijingguancha/f1072.html.

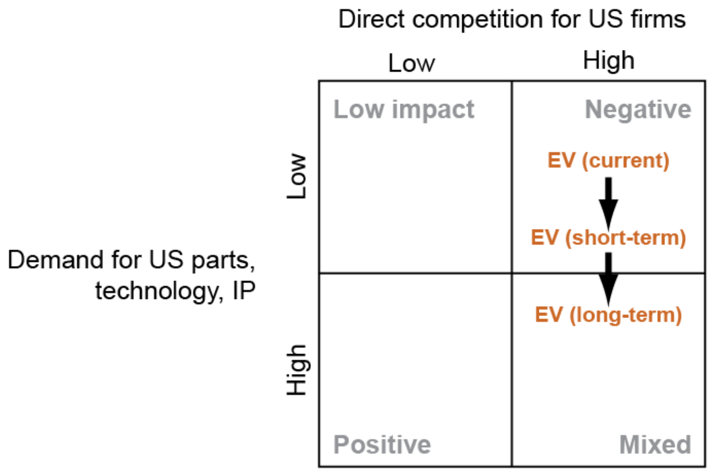
Technology transfer requirements pose an additional barrier to foreign EV makers seeking to enter the Chinese market. The Chinese government mandates joint ventures between foreign and Chinese auto companies for foreign companies to be able to manufacture within China. The foreign company has a minority stake in the joint venture.[826] This is a cost to foreign firms that must bring outside EV technology to China and then establish new domestic brands with EV options.[827] A 2009 MIIT regulation further required that one of the three EV key technologies—the battery system, drive system, or electronic control system—be controlled by the Chinese company in a joint venture. EV parts suppliers also must be in a joint venture.[828]

These requirements mean that China's EV market is dominated by local brands. The future of these policies remains uncertain, but it is hoped that China's current local protectionism in the EV market will be removed eventually, because these obstacles are seriously hindering the development of the Chinese EV industry, as well as making it difficult for China to achieve its goals of EV ownership. Additional barriers, such as the construction of EV charging infrastructure, also need to be addressed. As China further develops its EV industry regulations and infrastructure, it is expected that foreign firms will have better access to the Chinese market, creating positive effects for firms and economic competitiveness. This directional change, from currently negative implications to more of a mix of positive and negative implications for US economic competitiveness in the long run, is the only example in the case studies covered in this report to indicate a better long-term outcome for the United States (Figure 22).

As China's auto and EV policy environment eases toward foreign investment in the future, there will likely be an increased demand for US automobiles. A potential glimpse into this transition was given in January 2016 when the MOF stated that over the next few years, subsidies would be cut progressively and phased out completely in 2020. Expectations are that a zero emission vehicle policy and credit trading system similar to that in place in California will then be introduced.[829] With these changes, however, competition among local Chinese brands is still expected to be strong.

[826] USCC, "2015 Report to Congress of the US-China Economic and Security Review Commission," 84–86.
[827] Sabrina Howell, Henry Lee, and Adam Heal, "Leapfrogging or Stalling Out? Electric Vehicles in China," Harvard Kennedy School Belfer Center Discussion Paper, May 2014, http://belfercenter.ksg.harvard.edu/publication/24335/leapfrogging_or_stalling_out_electric_vehicles_in_china.html.
[828] Ibid.
[829] "New-Energy Vehicle Subsidies to End," *Global Times*, January 25, 2016, http://en.people.cn/business/n3/2016/0125/c90778-9008975.html.

Figure 22. Outcomes of Chinese investment in electric vehicles for US firms



High Speed Rail

High speed rail (HSR) offers a fascinating contrast to other industries emphasized by China's state S&T and industrialization plans. The HSR sector is an outlier in comparing the technological, industrial, and economic strengths and weaknesses of China and the United States, but could be a sign of things to come as China advances rapidly in important areas from which the United States is noticeably absent.

China has made swift progress in the adaptation and indigenization of HSR technology, which can be largely attributed to its IDAR model of technological advancement through absorption. By trading access to its huge market for technology transfer agreements, China successfully wooed industry leaders from Japan, France, Germany, and Canada to partner with local firms as it began construction of its national HSR network in the early 2000s. Along with the wind and solar industries, HSR in China demonstrates the strong arm that Chinese policymakers, state-owned enterprises, and regulators exercise in persuading foreign companies to enter contracts that boost the technology and know-how of Chinese national champions on highly advantageous terms. Often, these national champions become direct competitors to the foreign companies in China and overseas. In the HSR sector, China CSR Corporation (CSR) and China CNR Corporation (CNR) have become major international HSR suppliers.

Market Characteristics

Growth in the HSR global market is moderate, but the large size of individual contracts creates strong competition among industry leaders. In 2013, the global market totaled $102.3 billion and rose to $112.0 billion in 2014. It is expected to reach $133.4 billion by 2019, equaling a 3.6 percent CAGR over the next five years.[830] China's CSR (30 percent global market share) and CNR (18 percent global market share) dominate the market. These two firms merged in September 2015 to become CRRC Corporation, which will account for nearly half of the global market for HSR. Other leading countries and companies in the industry include Japan with 17 percent (Hitachi,

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[830] BCC Research, "Report Highlights," *High Speed Rail Technologies and Global Markets*, October 2014, http://www.bccresearch.com/market-research/engineering/high-speed-rail-technologies-markets-report-eng004a.html.

Kawasaki, Mitsubishi), France with 12 percent (Alstrom), and Germany with 6 percent (Siemens). Canada's Bombardier and Spain's Talgo are also large players.[831]

Global growth in HSR has been fueled by China's rapid expansion of its domestic railway network. By the end of June 2015, China's high speed network passed 20,000 kilometers. It is expected to open 2,000 more kilometers by the end of 2015.[832] This is up from the 16,000 kilometers it had completed at the end of 2014, a quantity larger than the HSR network in the entire European Union.[833]

The United States does not currently engage in high speed rail manufacturing. Indeed, while a leader in rail technology during the first half of the twentieth century, today the United States has maintained a strong presence only in the freight rail sector, which does not translate technology easily to the passenger service sector.[834] There is still a significant rail supply chain in the United States due to the large freight market, but the OEM and supplier base is dominated by foreign-owned firms, even though "Buy America" provisions in US law require that 60 percent of the value of the subcomponents of transit vehicles and equipment be produced in the United States, and that final assembly also occur in the country.[835] For example, four of the world's leading OEMs (Alstom, Bombardier, Kawasaki, Siemens) build their car shells in the United States but are not US-owned. Three of these (Alstom, Bombardier, and Kawasaki) each hold 25 percent of the US market share across all rail categories. However, consistent with "Buy American" requirements, just the final assembly occurs in the United States, and higher-value activities such as design, engineering, and systems integration are kept in the OEM's home country, or in locations nearer to larger markets.[836]

Technology Levels

China's HSR technology and designs are still predominantly based on foreign standards acquired in its initial drive to boost its domestic HSR network in the mid-2000s. Much of this technology has been indigenized and adapted to allow operation in the country's diverse terrains and climates.[837] However, China still faces many restrictions on its ability to export its HSR technology to foreign markets, although there is growing demand for Chinese HSR from many countries. Currently, China is developing a new "Chinese Standard" high-speed train, and test runs of the first prototype began in June 2015. The trains are designed to gradually replace the existing mix

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[831] Ibid.

[832] "High Speed Train Tenders Called as Domestic Prototype Starts Testing," *Railway Gazette*, July 20, 2015, http://www.railwaygazette.com/news/high-speed/single-view/view/high-speed-train-tenders-called-as-domestic-prototype-starts-testing.html.

[833] Zhao Lei, "China's High Speed Rail Network Is on the Global Fast Track," *Telegraph*, April 21, 2015, http://www.telegraph.co.uk/sponsored/china-watch/technology/11540416/chinas-high-speed-rail-network.html.

[834] Michael Renner and Gary Gardner, "Global Competitiveness in the Rail and Transit Industry," Worldwatch Institute, September 2010, http://www.worldwatch.org/system/files/GlobalCompetitiveness-Rail.pdf.

[835] Erik Pages, Brian Lombardozzi, and Lindsey Woolsey, "The Emerging US Rail Industry: Opportunities to Support American Manufacturing and Spur Regional Development," National Institute of Standards and Technology, June 2012, http://www.nist.gov/mep/upload/Rail-Report.pdf.

[836] Ibid.

[837] "High Speed Train Tenders Called as Domestic Prototype Starts Testing."

of domestic trains derived from international designs, and also allow Chinese suppliers to bid in markets that are currently excluded under their licensing agreements with foreign partners.[838]

Low costs are a significant advantage of China's large investment in HSR technology. In a press briefing in January 2015, the MOFCOM cited a recent World Bank report that the price per kilometer of China's high speed rail was RMB 87–129 million ($13.53–$20.1 million), while those of European countries range from RMB 150–240 million ($23.33–$37.32 million). This puts China's HSR costs at nearly half that of European rivals. Japan reportedly has costs similar to Europe. Furthermore, China's construction period is reported to be three-quarters of that of developed countries.[839] China's low costs and shorter construction periods are due to a number of factors. According to the World Bank, these include cheaper labor, development of competitive multiple local sources (a result of announced state plans for construction), large volumes, relatively low cost of land acquisition and resettlement, and standardization of designs for embankments, track, viaducts, electrification, signaling and communication systems.[840]

Policy Measures

HSR first entered China's state S&T plans in the 2006–2020 MLP. Later, a 2008 Joint Action Plan for Indigenous Innovation of China's High Speed Rail (中国高速列车自主创新联合行动计划) issued by MOST and the Ministry of Railways was key in setting out goals for the industry. These included developing HSR with speeds of 350 km per hour, pushing forward a Beijing-Shanghai HSR link, and ultimately becoming a global leader in HSR technology.[841] In 2012, MOST issued the 12th Five-Year Special Plan for High Speed Rail Technology Development, which further set strategic requirements and key technologies for the industry. Today, the sector continues to receive top-level attention with advanced rail transportation identified as one of the ten focus industries of the Made in China 2025 plan.

Developments continue to occur in China's policy to promote HSR. In early 2015, China Railway Corporation, successor of the former Ministry of Railways, established China Railway International Ltd. to coordinate Chinese companies' overseas development.[842] Also, during a State Council meeting in January 2015, Premier Li Keqiang urged government departments to boost the overseas expansion of Chinese-developed industrial equipment, including high speed rail.[843] A news briefing by MOFCOM shortly after Li's remarks noted that "the 'going global' strategy of Chinese railway export is changing from the initial equipment supply mode to the whole industry-chain

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838 Ibid.

839 Ministry of Commerce, "Ministry of Commerce's News Briefing on China's Export of Railway Equipment," February 9, 2015, http://english.mofcom.gov.cn/article/newsrelease/press/201502/20150200899206.shtml.

840 Gerald Ollivier, Jitendra Sondhi, and Nanyan Zhou, "High Speed Railways in China: A Look at Construction Costs," *China Transport Topics*, No. 9, July 2014, 8, http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/07/04/000333037_20140704083655/Rendered/PDF/892000BRI0Box3000china0transport09.pdf.

841 Ministry of Science and Technology, "科技部、铁道部联合签署《中国高速列车自主创新联合行动计划合作协议》" [Ministry of Science and Technology and Ministry of Railways Signed China's Joint Action Plan of High Speed Rail Indigenous Innovation], February 27, 2008, http://www.most.gov.cn/tpxw/200802/t20080227_59350.htm.

842 Zhao Lei, "China's High-Speed Rail Network Is on the Global Fast Track."

843 Ibid.

output mode encompassing design and technical guidance, project construction, and operation and maintenance."[844]

Implications for the United States

The creation of CRRC through the merger of China's two HSR national champions CSR and CNR changes the competitive nature of Chinese HSR. Individually, CSR and CNR were outbidding foreign competitors in major projects (although rarely bidding against each other). They will have even more leverage under CRRC, which has a market capitalization of $130 billion.[845] Furthermore, the formation of CRRC will eliminate the sometimes harmful undercutting occurring between CSR and CNR.[846] CRRC is now the world's second-largest industrial company, second only to General Electric, and will compete aggressively for projects across Africa, Southeast Asia, and Latin America.[847] As one industry expert explained, "It used to be that CSR and CNR were competing against Bombardier and Alstom; now it has become China versus everybody else."[848]

As part of its 'rail diplomacy,' China is using its state-owned rail firms not always to win profitable contracts, but to project its global influence. For example, in October 2015, Indonesia confirmed that it chose China's HSR bid over Japan's to build its first high speed railway, because China proposed to complete the project without any guarantee of funding from Indonesia.[849] Indonesia had initially declined bids from both China and Japan due to high costs and planned to downgrade its plans and instead construct a medium-speed railway. Globally, this action by China threatens competition in the HSR industry as China relies on its state-backed financing to secure contracts. Precise numbers or even the scale of this government support is unknown.

In the United States, China's continued investment in HSR benefits US firms and the US economy. The low costs of Chinese competitors provide incentives for other foreign competitors to lower prices and allows for lower price thresholds during bid tenders. Buy America requirements in the rail industry also mean that much of the manufacturing would occur in the United States, supporting industrial supply chains. As noted earlier, in the current US rail industry, many foreign companies establish subsidiaries in the United States to meet this requirement. A CRRC investment in the United States, however, would facilitate the development of the domestic rail subcomponent industry and support a large blue-collar workforce.

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844 "Ministry of Commerce's News Briefing on China's Export of Railway Equipment."

845 Lauren Dodillet, "Merger of China's Two Largest Rail Companies Forms $26 Billion Firm," *China Business Review*, January 14, 2015, http://www.chinabusinessreview.com/merger-of-chinas-two-largest-rail-companies-forms-26-billion-firm/.

846 "Mega Merger Ahead as China's CNR + CSR = CRRC Corporation," *SmartRail World,* January 5, 2015, http://www.smartrailworld.com/mega-merger-ahead-as-chinas-cnr-csr-crrc-corporation.

847 Lily Kuo, "China's Newest Corporate Giant Is Selling Cheap High-Speed Rail to the Rest of the World," QUARTZ, June 8, 2015, http://qz.com/422070/chinas-newest-corporate-giant-is-selling-cheap-high-speed-rail-to-the-rest-of-the-world/.

848 Bloomberg Business, "With a Rail Merger, China Is Forging an Industrial Giant Second Only to GE," June 8, 2015, http://www.bloomberg.com/news/articles/2015-06-07/china-forges-industrial-giant-second-only-to-ge-with-rail-merger.

849 Shannon Tiezzi, "It's Official: China, Not Japan, Is Building Indonesia's First High-Speed Railway," *Diplomat,* October 1, 2015, http://thediplomat.com/2015/10/its-official-china-not-japan-is-building-indonesias-first-high-speed-railway/; "Uncovering Secrets: How Far is China from Getting Indonesia's High-Speed Railway?" Xinhua Net, October 2, 2015, http://news.ifeng.com/a/20151002/44778112_0.shtml.

This impact can be seen in a recent $566 million CRRC contract from the state of Massachusetts and the Massachusetts Bay Transportation Authority (MBTA) to build new subway cars. In September 2015, CRRC USA Rail Corporation, a CRRC subsidiary, broke ground on a $95 million subway car factory in Springfield, Massachusetts. The plant is expected to have a permanent staff of 150, with minimum salaries of $66,000 a year, starting in 2017. The construction of the plant is estimated to lead to the hiring of another 150 workers. The plant will give CRRC a foothold in the North American market, according to Chanhe Zhou, president of CRRC USA Rail Corporation.[850]

On September 2015, a group of Chinese firms including CRRC announced a deal between their Nevada-based venture China Railway International USA and US partner XpressWest to build a 370-km high-speed link from Las Vegas to Los Angeles. Chinese and US companies will establish a joint venture to construct and operate the high speed railway. It is estimated that the total investment will reach $12.7 billion. Although this project will likely offer Chinese firms little financial benefit, it will be significant for China's long-term goals. Indeed, China's entry into the US rail industry is expected to trigger a domino effect on several other HSR projects in the United States, including one in California to connect Los Angeles and San Francisco.[851]

China's HSR industry differs from most other industries in its implications for US competitiveness. US firms operating in China are not affected by China's HSR growth due to a lack of strong US expertise in the field. Indeed, prior to the recent development of China's HSR industry, US firms competing in this area would have faced similar competition from other global leaders in France, Germany, Japan, and Canada. The most imminent implication from China's HSR industry is the warning it provides foreign companies in other industries that technology transfers to Chinese firms could lead to the creation of local national champions that will compete with them in local markets and eventually in international markets.

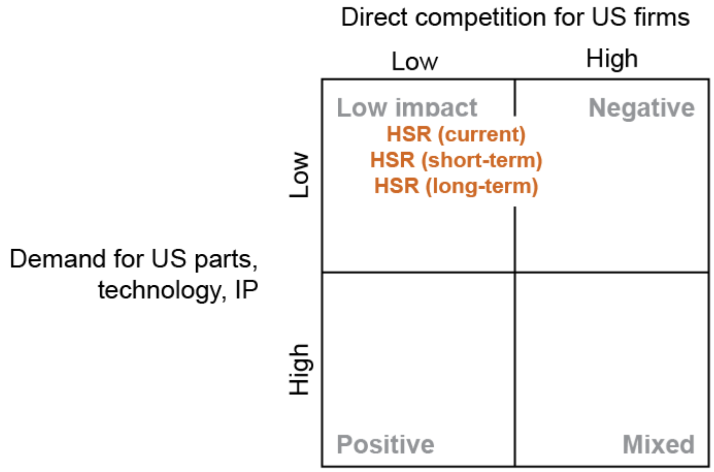
To maintain consistency with the other case studies, the conclusions about China's impact on US economic competitiveness primarily look at the effects within China (see Figure 23). Direct competition for US firms in this case is low, but not because of a lack of government policies favoring local actors. Indeed, if the United States had a leading HSR company, then competition would be very high. Demand for US parts, technology, and IP is also currently low and is expected to remain low, as the United States has no policies in place to develop this industry. This results in an overall low impact on US economic competitiveness.

It should be reemphasized that there could be some positive implications domestically in the United States from China's HSR development. This is dependent on several factors, especially demand and public support for HSR in the United States, and on the bidding process between Chinese HSR firms and other competitors. If other factors align, however, it is certain that Chinese competition will provide a low-cost alternative for HSR construction.

[850] Jim Kinney, "Chinese CRRC USA Rail Corp. Breaks Ground On $95 Million Subway Car Factory in Springfield," Mass Live, September 3, 2015, http://www.masslive.com/business-news/index.ssf/2015/09/chinese_crrc_usa_rail_corp_breaks_ground.html.

[851] Brenda Goh, "China Firms Sign Deal for High-Speed Las Vegas-Los Angeles Rail Link Ahead of Xi's US Visit," Reuters, September 18, 2015, http://www.reuters.com/article/2015/09/18/us-china-usa-railways-idUSKCN0RH09J20150918; Sina Finance, "China Will Construct High-Speed Railway in the US and the Construction Work Will Begin from September 2016," September 17, 2015, http://finance.sina.com.cn/world/20150917/105223274378.shtml.

Figure 23. Outcomes of Chinese investment in high speed rail for US firms



Biopharmaceuticals

The mainstream definition of biopharmaceuticals is "pharmaceuticals that are biological in nature and manufactured by biotechnology methods." This includes monoclonal antibodies, recombinant proteins, proteins and vaccines derived from non-engineered organisms and blood/plasma-derived products.[852] The biopharmaceutical industry is a major subindustry under the pharmaceutical industry. It is classified as a high-value, knowledge-based industry and ranks among the most innovative advanced manufacturing industries.[853] The United States is currently the world leader in terms of R&D and manufacturing, while China lags significantly with an unbalanced production structure and weak independent R&D capability.

Market Characteristics

The global biopharmaceutical market totaled $163 billion in 2014, accounting for 20 percent of the overall global pharmaceutical market.[854] The annual growth rate in the last few years has been around 15−18 percent.[855] Persistence Market Research estimates that the global market value will reach $278 billion by 2020.[856]

The US biopharmaceutical market is expected to increase to $144 billion by 2016, growing at a CAGR of 11.2 percent, driven by the launch of new products, approval of existing therapies and

852 Ronald A. Rader, "Redefining Biopharmaceutical," *Nature Biotechnology* 26 (2008): 743−51, doi: 10.1038/nbt0708-743.
853 Battelle and the Pharmaceutical Research and Manufacturers of America, "The US Biopharmaceutical Industry: Perspectives on Future Growth and the Factors That Will Drive It," December 2009, 13, http://www.phrma.org/sites/default/files/pdf/2014-economic-futures-report.pdf.
854 Ralf Otto, Alberto Santagostino, and Ulf Scraeder, "Rapid Growth in Biopharma: Challenges and Opportunities," December 2014, McKinsey.com, http://www.mckinsey.com/insights/health_systems_and_services/rapid_growth_in_biopharma.
855 "2015 年全球仿制药市场规模预测" [2015 Global Market Forecast of Biosimilars], 前瞻网 [qianzhan.com], January 8, 2015, http://bg.qianzhan.com/report/detail/361/150106-29c01f87.html.
856 Persistence Market Research, "Global Biopharmaceuticals Market Is Expected to Reach US$2,78,232.9 Mn by 2020," July 27, 2015, http://www.persistencemarketresearch.com/mediarelease/biopharmaceutical-market.asp.

drugs for additional diseases and conditions , and the rising number of people aged 65 years and above.[857]

China is the world's third largest biopharmaceutical market, after Japan.[858] Projections place China's biopharmaceutical market at $66 billion in 2015 (up from $52 billion in 2014), growing at an average rate of 28 percent.[859] This growth is driven by rising awareness about healthcare, a large and aging population, increases in total and per capita spending on healthcare, and supportive measures in various 12th five-year plans and other industry specific plans.[860] Fu Mingzhong, executive president of the China Association of Pharmaceutical Commerce, predicts that China's biopharmaceutical market will reach between $91 and $121 billion in the future. IMS Health predicts that by 2020, China will become the world's second largest biopharmaceutical market after the United States.[861]

Technology Levels

The United States has been the world leader in biopharmaceutical R&D and the development of new medicines over the past 30 years, but Japan and Europe are catching up.[862] The United States leads the world in biopharmaceutical publications, IP generation, overall clinical trial activity, and early-stage clinical research.[863] The biopharmaceutical pipeline has more than 5,000 new medicines in development around the world, with approximately 3,400 compounds currently being studied in the United States.[864] In addition, more than 70 percent of worldwide venture capital investments in high-growth-potential biopharmaceutical start-ups are made in the United States.[865] US firms such as Gilead Sciences, Allergen, Celgene, Biogen Idec, Regeneron Pharmaceuticals, Amgen, Alexion Pharmaceuticals, and Vertex Pharmaceuticals are leading global biopharmaceutical players.

China's biopharmaceutical industry, on the other hand, has an unbalanced production structure, even though it covers the whole value chain. It is, however, especially strong in contract research

857 "Strategic Analysis and Forecast of US Biopharmaceutical Industry (2009–2016): Impact of Healthcare Reform, Technological Innovation, and Market," February 2011, marketsandmarkets.com, http://www.marketsandmarkets.com/Market-Reports/biopharmaceutical-323.html.

858 "生物制药临机遇：靠创新和特色提升国际竞争力" [Opportunities for the Biopharmaceutical Industry to Enhance International Competitiveness Through Innovation], 中国经济导报 [*China Economic Herald*], May 22, 2012, http://www.ceh.com.cn/ceh/jryw/2012/5/22/114078.shtml.

859 "到 2015 年我国生物制药行业市场规模有望突破 4000 亿元" [Market Size of Chinese Biopharmaceutical Industry Is Expected to Exceed 400 Billion Yuan], 前瞻网 [qianzhan.com], May 9, 2013, http://www.qianzhan.com/analyst/detail/220/130509-39276579_3.html.

860 Deloitte, "China's Pharmaceutical Market: Summary and Prospects," in "The Next Phase: Opportunities in China's Pharmaceuticals Market," http://www2.deloitte.com/content/dam/Deloitte/ch/Documents/life-sciences-health-care/ch_Studie_Pharmaceutical_China_05052014.pdf.

861 "生物医药产业规模有望达到 6000-8000 亿元" [Market Size of the Biopharmaceutical Industry Is Expected to Reach RMB 600 to 800 Billion], 中证网 [*China Securities Journals*], December 24, 2014, http://www.cs.com.cn/xwzx/cj/201412/t20141224_4599564.html.

862 "The US Biopharmaceutical Industry."

863 Ibid.

864 "The Pharmaceutical and Biotech Industries in the United States," SelectUSA website, accessed September 14, 2015, http://selectusa.commerce.gov/industry-snapshots/pharmaceutical-and-biotech-industries-united-states.html.

865 The US Biopharmaceutical Industry," 13.

organizations (CRO) and biosimilar production. The industry has insufficient capacity on high-end products and overcapacity for lower-end products. China has become one of the leading players in recombinant protein drugs but is far behind in R&D on monoclonal antibodies. More than 70 percent of biopharmaceutical products developed in China are still at the pre-clinical or Phase I clinical trial stages. Chinese biopharmaceutical companies have developed few breakthrough products and mainly produce generic drugs and active pharmaceutical ingredients. Among the 382 kinds of genetically engineered drugs and vaccines that are approved for listing on the market by the Chinese authorities, only 21 are innovator drugs (brand-name drugs licensed by Chinese firms). The rest are generic drugs.[866]

However, China is Asia's leader in biopharmaceutical industry R&D spending and number of companies. According to Genetic Engineering & Biotechnology News, China has around 7,500 biopharmaceutical firms, which spent $336.5 billion in R&D in 2013.[867] Industry experts argue that these Chinese firms are small in scale and have low concentration ratios.[868] While the overall industry investment is huge, the existence of too many small- and medium-size companies has resulted in limited funding for any single specific project. In fact, Chinese biopharmaceutical companies lack indigenous R&D capabilities.[869] Domestic companies' R&D to total sales ratio is much lower than multinational corporations. For example, China's top R&D investor, Jiangsu Heng Rui Medicine, spent RMB 563 million ($87.5 million) in R&D in 2013, accounting for 9 percent of its sales for that year. This number, however, is significantly lower than top multinationals such as Pfizer, which spent 13.9 percent of its $6.25 billion sales on R&D in the same year.[870] In addition, the Chinese biopharmaceutical industry suffers from low conversion rates of academic research, poor marketing strategies, and constraints within China's current health insurance system.[871]

Policy Measures

Since 2000, the Chinese government has paid heightened attention to biopharmaceutical research, development, and production and shifted its policy goals to catching up to international standards and perhaps even make China a world leader in biotechnology research. Several methods have been used, including a faster drug registry for biopharmaceutical products, which expedites the process of introducing a new drug to market, and policies to promote R&D and the establishment of industrial parks for biopharmaceutical firms.[872] In 2012, the State Council formally identified the biomedical industry as one of the country's SEIs. During the 12th FYP, China invested RMB 10 billion ($1.55 billion) in innovation funds for the biotechnology industry, which has a special

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866 Fang Pengfei, "制造业发展报告: 生物医药产业发展现状及对策" [Manufacturing Industry Report: Biopharmaceutical Industry Development Status], 中国社会科学网 [*Chinese Social Sciences Net*], June 5, 2015, http://www.cssn.cn/dybg/gqdy_jj/201506/t20150625_2046467_14.shtml, 15.
867 Alex Philippidis, "Top 8 Asian Biopharma Clusters 2015," Genetic Engineering and Biotechnology News, March 20, 2015, http://www.genengnews.com/insight-and-intelligence/top-8-asian-biopharma-clusters-2015/77900413/.
868 Fang Pengfei, "Manufacturing Industry Report," 16.
869 Ibid.
870 Ibid.
871 Ibid.
872 Hao Hu and Chao-Chen Chung, "Biopharmaceutical Innovation System in China: System Evolution and Policy Transitions (Pre-1990s–2010s)," *International Journal of Health Policy and Management* (2015): 5, http://www.ijhpm.com/article_3091_0.html.

focus on the biopharmaceutical industry.[873] This fund is not comparable to the level of investment of US government agencies like the National Institutes of Health, which appropriated $6.1 billion in funding for biotechnology research in fiscal year 2012, but does represent an increase of 52 percent over the 11th FYP.[874]

To further boost the development of the biotechnology industry, the State Council issued the Biotechnology Industry Development Plan (生物产业发展规划) in late 2012, which defined the biopharmaceutical industry as a top priority with goals of improving industry concentration and share of the global market.[875] The 12th Five-Year Plan for Biotechnology Development (十二五生物技术发展规划) issued by MOST in 2012 sets making breakthroughs in biopharmaceutical technology as a key task. Both plans have committed to provide support through initiatives such as building pilot industrial and service bases, increasing financial investment through special funds and venture capital, and strengthening the intellectual property system to encourage innovation. The MOST plan also encourages international collaboration by supporting domestic companies in efforts to: 1) establish overseas R&D centers; 2) cultivate partnerships with leading multinational companies to develop new products and expand global markets; and 3) take advantage and learn from imported technology.[876]

Implications for the United States

The biopharmaceutical industry supported 3.4 million jobs, including 814,000 direct jobs, 1,022,000 indirect jobs, and 1,528,000 induced jobs across the US economy in 2011. It helps support a vibrant scientific and economic ecosystem that is vital to the US economy and US global competitiveness.[877] Development in China, specifically the government's drive to build a strong domestic biopharmaceutical industry, poses both opportunities and challenges for US firms in this industry.

China is the world's third largest biopharmaceutical market and is experiencing significant growth. The Chinese government unveiled a major healthcare reform effort in 2009 and committed RMB 850 billion ($132.2 billion) to develop the country's healthcare system.[878] Healthcare spending in China is likely to grow further, which in turn presents opportunities for US biopharmaceutical firms. US firms can further penetrate China's biopharmaceutical market through exports and by establishing a local presence within the country.

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873 "创新基金 100 亿重点扶持生物制药企业" [10 Billion Innovation Fund to Specially Support Biopharmaceutical Company], 中国制药网 [www.zyzhan.com], September 19, 2011, http://www.zyzhan.com/news/detail/16395.html.

874 National Institutes of Health, "Estimates of Funding for Various Research, Condition, and Disease Categories (RCDC)," February 5, 2015, https://report.nih.gov/categorical_spending.aspx.

875 "国务院关于印发生物产业发展规划的通知" [The State Council's Notice on Issuing the Plan of Bioindustry Development], PRC Central Government website, December 29, 2012, http://www.gov.cn/zwgk/2013-01/06/content_2305639.htm.

876 Ministry of Science and Technology, "关于印发十二五生物技术发展规划的通知" [Notice to Issue 12th Five-Year Bio-Technology Development Plan], November 14, 2011, http://www.most.gov.cn/fggw/zfwj/zfwj2011/201111/t20111128_91115.htm.

877 Pharmaceutical Research and Manufacturers of America, *2015 Biopharmaceutical Research Industry Profile* (Washington, DC: PhRMA, 2015), http://www.phrma.org/sites/default/files/pdf/2015_phrma_profile.pdf.

878 Deloitte, "China's Pharmaceutical Market: Summary and Prospects."

Besides being an attractive market, China is an alternative source of R&D funding. Significant funding has been poured into R&D by both the public and corporate sectors. China's CAGR of biomedical R&D expenditures was 32.8 percent per year between 2007 and 2012, significantly higher than the CAGR of −1.9 percent in the United States. Foreign players can take advantage of this increase in R&D budgets, particularly those allocated by the Chinese government to acquire novel intellectual property or establish in-house R&D, through partnering with local firms as well as universities and research institutes.[879]

There is currently little direct competition between US firms and Chinese firms in this sector, mainly because of a huge technology gap. However, the continued success of the United States as a world leader in biopharmaceutical innovation cannot be taken for granted. In response to declining R&D productivity, the US pharmaceutical industry has decreased its cost base by outsourcing some drug research.[880] China is increasingly the preferred destination for such outsourced work because of a large and qualified talent pool and low operational costs.[881] It has been a major driver of the growth of the Chinese CRO industry, which has successfully "transitioned from the early years of niche outsourcing to achieving a large scale and breadth of service offerings, thereby contributing significantly towards innovation output in China."[882] As US biopharmaceutical companies continue to outsource their R&D operations to China, their domestic R&D facilities are likely to be negatively affected, potentially resulting in closures and layoffs.[883]

Additionally, Chinese scientists who have trained in the United States and returned home have become an important source of transfer of mature biopharmaceutical S&T knowledge and expertise. While strengthening the capabilities of China's domestic biopharmaceutical industry, these returnees may also create risks for US firms by making them targets of intellectual property theft. GlaxoSmithKline filed charges in January 2016 against five Chinese nationals for stealing biopharma secrets. Two of the five are scientists in Glaxo's research facilities in Upper Merion, Pennsylvania.[884] Chinese pharmaceutical firms have also experimented with acquiring biopharmaceutical technology from overseas through patent acquisition or technology cooperation. Through such direct knowledge transfers, China could eventually narrow the gap with the frontiers of global biopharmaceutical development and rapidly establish an industrial infrastructure.[885] If this happens, US firms would face more direct competition with domestic firms in China in both the short and long term (Figure 24).

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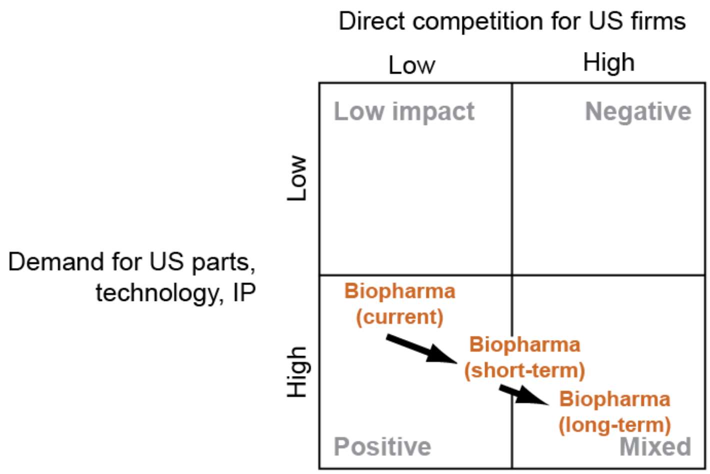
[879] Xuefei Mao, "Entering China's Emerging Life Sciences Markets: The Opportunity for Ontario Startups," MaRS Market Insights—Going Global Series: China, December 2014, http://www.marsdd.com/wp-content/uploads/2014/12/Going-Global-China-Part-2.pdf.
[880] Christine Xia and Ajay Gautam, "Biopharma CRO Industry in China: Landscape and Opportunities," *Drug Discovery Today* 20 (2015): 794–98.
[881] Author interview with Yanzhong Huang, Senior Fellow for Global Health, Council on Foreign Relations, January 22, 2016.
[882] Xia and Gautam, "Biopharma CRO Industry in China."
[883] Author interview with Yanzhong Huang.
[884] "Five Accused of Stealing Drug Secrets from GlaxoSmithKline," *New York Times*, January 20, 2016, http://www.nytimes.com/2016/01/21/business/5-accused-of-stealing-drug-secrets-from-glaxosmithkline.html?_r=0.
[885] Hu and Chung, "Biopharmaceutical Innovation System in China."

Figure 24. Outcomes of Chinese investment in biopharmaceuticals for US firms



Medical Devices

The medical device industry is another research-intensive subsector of the pharmaceuticals industry. According to the World Health Organization, a medical device is "[a]n article, instrument, apparatus, or machine that is used in the prevention, diagnosis, or treatment of illness or disease, or for detecting, measuring, restoring, correcting, or modifying the structure or function of the body for some health purpose."[886] The key products that comprise this industry include surgical appliances and supplies, surgical and medical instruments, electro-medical equipment, in-vitro diagnostic substances, irradiation apparatus, and dental and ophthalmic goods.[887] The US Food and Drug Administration categorizes devices into three classes based on the relative risk they may pose to patients' health and the level of control necessary to assure the safety and effectiveness of the device. Class One includes devices with the lowest risk, such as tongue depressors and bandages. Class Two devices are higher risk than Class One and require greater regulatory controls. Examples include x-ray systems and surgical drapes. Class Three includes those with the greatest risk, such as heart valves.[888] China classifies its devices on a similar basis.[889]

As in the biopharmaceutical industry, there is a big technology gap between the United States and China, where the United States holds a leading position and China significantly lags behind. This gap, considering the current status of Chinese medical devices industry and the complexity of this industry, is not going to close up anytime in the foreseeable future. The United States is China's leading supplier of medical devices. Given forecasts of flat growth in US healthcare spending, the

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[886] World Health Organization, "Definitions Health Technology," accessed January 28, 2016, http://www.who.int/medical_devices/definitions/en/.
[887] International Trade Administration, Office of Health and Consumer Goods, "Medical Devices Industry Assessment," http://ita.doc.gov/td/health/medical%20device%20industry%20assessment%20final%20ii%203-24-10.pdf.
[888] US Food and Drug Administration, "Classify Your Medical Device," accessed January 28, 2016, http://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/Overview/ClassifyYourDevice/.
[889] Sarah Collins, "What Are the Medical Device Approval Processes in Major Markets?" Market Realist website, November 9, 2015, http://marketrealist.com/2015/11/medical-device-approval-processes-major-markets/.

rapid growth of the Chinese market presents great opportunities for US medical device manufacturers.

Market Characteristics

The global market for medical devices was $350 billion in 2014.[890] Driven by aging populations, increasing healthcare expenditures in emerging markets and technology advances, researchers have predicted that the global medical devices market will grow at a steady rate, with sales revenue reaching $543.9 billion by 2020.[891]

The United States is the largest medical device market at around $110 billion.[892] US healthcare spending, which includes acquiring medical devices and reimbursing the cost of procedures using medical devices, is the world's highest.[893] It accounted for 17.5 percent of GDP in 2014, reaching $3.0 trillion or $9,523 per person.[894] However, due to recent reductions in reimbursements, the Patient Protection and Affordable Care Act, and decreased healthcare spending by patients and hospitals, the rate of growth in US healthcare spending is expected to flatten in the coming years, which may reduce demand for medical devices in the United States.[895]

China's medical devices market, on the other hand, is experiencing rapid growth. Ranked second largest in the world, China's market reached $38.7 billion in 2014, with a year-to-year growth rate of 20 percent.[896] An aging population, economic growth, and increased government investment in healthcare are the big drivers of China's medical device market.[897] Some sources estimate that the Chinese market will grow to $70−80 billion in 2015.[898] However, China's medical device industry only accounts for 19 percent of the domestic pharmaceutical industry, while the global medical devices market to total pharmaceutical market ratio is around 42 percent.[899] In addition to the relatively young age of Chinese medical devices industry, this gap is due to the lasting abnormal

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[890] Yair Holtzman, Gleb Gorkhover, and Michael Ganz, "The US Medical Device Industry: Strengths, Weaknesses, Opportunities, and Threats," January 12, 2015, MDDIonline.com, http://www.mddionline.com/article/us-medical-device-industry-swot-analysis-01-12-2015.

[891] MedGadget, "Global Medical Devices Market 2012–2020: Market Size, Share, Trends, Analysis and Forecast," September 25, 2015, http://www.medgadget.com/2015/09/global-medical-devices-market-2012-2020-market-size-share-trends-analysis-and-forecast.html.

[892] US Department of Commerce, "The Medical Device Industry in the United States," SelectUSA website, accessed September 14, 2015, http://selectusa.commerce.gov/industry-snapshots/medical-device-industry-united-states.

[893] Mihir P. Torsekar, "US Medical Devices and China's Market: Opportunities and Obstacles," USITO, Office of Industries Working Paper No. ID-036, June 2014, http://www.usitc.gov/publications/332/id-036workingpaperusmedicaldevicesfinalss.pdf.

[894] "Historical," Centers for Medicare and Medicaid Services, December 3, 2015, https://www.cms.gov/research-statistics-data-and-systems/statistics-trends-and-reports/nationalhealthexpenddata/nationalhealthaccountshistorical.html.

[895] Torsekar, "US Medical Devices and China's Market."

[896] "2014 中国医疗器械行业发展蓝皮书" [2014 Blue Book of China's Medical Device Industry], 中国医药物资协会 [China Medical Pharmaceutical Material Association], March 10, 2015, http://news.bioon.com/article/6666770.html.

[897] Torsekar, "US Medical Devices and China's Market."

[898] "2013 年我国医疗器械行业发展现状和存在问题" [2013 Status and Problems of Chinese Medical Device Industry], 中国医疗器械行业协会 [China Association for Medical Devices Industry], March 18, 2014, http://www.bioon.com/industry/instrumentreport/592865.shtml.

[899] "2014 Blue Book of China's Medical Device Industry."

industry rule—"drug-maintaining-medicine" (以药养医).[900] Starting in the 1980s, hospitals were allowed to raise drug prices to make up for shortfalls in government funding. Today, profits from drug sales account for 40 to 50 percent of hospital revenue. Drug sales rebates are also an important source of income for doctors in China, who would otherwise have relatively low salaries.[901] This rule provides incentives for doctors and hospitals to prescribe drugs instead of using medical devices. The low usage ratio of medical devices, on the other hand, also indicates substantial growth potential.[902]

The United States also has the world's largest medical device industry by production value. There are more than 7,000 medical devices companies in the United States, most of them SMEs that employ less than 100 people. The industry supports around 1.9 million jobs in the United States.[903] Seven of the world's ten largest medical device OEMs, ranked by 2012 revenue, are headquartered in the United States. These include Johnson & Johnson, GE Healthcare, Medtronic, Baxter International, Abbott Laboratories, Cardinal Health, and Stryker. The United States was also one of the world's leading exporters of medical devices, and particularly a leading medical devices supplier to China.[904] Exports of US medical devices reached $45 billion in 2014.[905] In 2015, US exports to China of medical devices totaled $2.57 billion, accounting for 34.3 percent of China's total imports.[906]

Technology Levels

The United States is considered the world's leader in medical device innovation, which is reflected in the amount of resources that companies direct towards R&D. However, most of these resources are directed towards improving existing devices, rather than to introducing novel technologies.[907] China's medical device industry is at the intermediate or lower level in global competition. Although indigenous manufacturing of medical devices occurs in China, this production has traditionally been inadequate to meet the country's demand for high-technology medical devices.[908] China has 16,000 medical device manufacturing companies, but only 17 percent produce high-tech products.[909] GE, Phillips, and Siemens take more than 80 percent of the market of several

[900] 媒体:中国医疗器械消费占药品 14% 国际比例为 1:1" [Media: Chinese Consumption of Medical Devices Is 14 Percent of Drugs, While This Ratio Globally Is One to One], 网易新闻 [NetEase], August 18, 2014, http://news.163.com/14/0818/00/A3T2NGQJ00014SEH.html.
[901] "人民日报不吐不快："以药养医"等于"以药毁医"" [People's Daily's Opinion: "Drug-Maintaining-Medicine" Is Actually "Drug-Destroying-Medicine"], *People's Daily*, July 26, 2013, http://opinion.people.com.cn/n/2013/0726/c1003-22332165.html.
[902] "2014 Blue Book of China's Medical Device Industry."
[903] "Pharmaceutical & Medical Device Companies Target China," GlobalVision International website, accessed January 29, 2015, http://globalvis.com/2015/12/pharmaceutical-medical-device-industries-china/.
[904] Torsekar, "US Medical Devices and China's Market."
[905] Curt Cultice, "Exports a Growing Opportunity for US Medtech Firms," DeviceTalk blog, September 10, 2015, http://www.mddionline.com/blog/devicetalk/exports-growing-opportunity-us-medtech-firms.
[906] US Census, "US Exports to China by 5-digit End-Use Code 2005–2014," http://www.census.gov/foreign-trade/statistics/product/enduse/exports/c5700.html; "2014 Blue Book of China's Medical Device Industry."
[907] "US Medical Devices and China's Market: Opportunities and Obstacles."
[908] Ibid.
[909] "2014 Blue Book of China's Medical Device Industry."

large-scale medical devices including CT, MRI, nuclear medicine, and angiography.[910] In the low-end market, there are excessive numbers of Chinese companies competing on similar products.[911]

Additionally, most of China's manufacturers are small in scale. About 90 percent of the companies in the medical device industry are low-tech SMEs with annual revenues of RMB 10 to 20 million ($1.55 to 3.11 million).[912] Even the country's large manufacturers have not reached the scale of the top multinationals. In 2014, total sales of the 20 medical device companies listed on China's stock markets were $6 billion, accounting for only 14.5 percent of the market.[913] The industry also has a low R&D input ratio, low innovation capability, and few core technologies. Overall, the R&D expenditure of the Chinese medical device industry is only 3 percent of its total sales, while the international average ratio is more than 15 percent.[914] As a result of low production scale and R&D investment, China has weak development and innovation capability and has not developed many original technologies and products.[915]

In contrast, US medical device companies are known for innovation and high-technology products. The United States also holds a competitive advantage in several industries that the medical device industry relies upon, including microelectronics, telecommunications, instrumentation, biotechnology, and software development.[916] As an industry expert noted, the medical devices industry is multi-disciplinary, knowledge-intensive, and capital-intensive.

In addition to insufficient funding for R&D, China also lacks risk investment mechanisms and solid information technology to support the development of medical devices.[917] As these issues are unsolved, the technology gap between China and the United States will not be closed anytime soon.

Policy Measures

The Chinese government has supported the development of the medical device industry in six ways:[918]

1. In the 12th FYP, China set the goal of establishing ten national engineering and technology research centers and national key laboratories to strengthen its medical device R&D capability.
2. China supports development of regional industrial clusters and announced it would establish eight to ten national technological industrial bases during the 12th FYP.

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910 "高端医疗设备市场低国产化 外资"三巨头"占八成" [Low Localization in High-End Medical Equipment Market, Foreign "Big Three" Account for Eighty Percent], 网易财经 [NetEase], March 28, 2015, http://money.163.com/15/0328/00/ALON5DNT00253B0H.html.

911 "2014 Blue Book of China's Medical Device Industry."

912 "Media: Chinese Consumption of Medical Devices Is 14 Percent of Drugs."

913 "2014 Blue Book of China's Medical Device Industry."

914 "2013 Status and Problems of Chinese Medical Device Industry."

915 Ibid.

916 Select USA, "The Medical Device Industry in the United States."

917 "Media: Chinese Consumption of Medical Devices is 14 Percent of Drugs."

918 Ministry of Science and Technology, "关于印发医疗器械科技产业"十二五"专项规划的通知" [Notice to Issue Medical Industry Special 12th Five-Year Plan], December 31, 2011, http://www.gov.cn/zwgk/2012-01/18/content_2048053.htm.

3. China provides financial support to the industry through special funds established by NDRC and MOST for high-end medical equipment R&D.
4. China protects domestic companies and products. For example, it gives priority to domestic firms for government procurement on medical devices and restricts foreign devices using regulatory measures.[919] The MOFCOM responded to domestic manufacturers' requests for an anti-dumping investigation against the European Union and Japan on hemodialysis equipment in 2014.[920] An officer from the ministry noted that the investigation is also a response to government's policy on accelerating the development of domestic high-end medical devices.[921]
5. China has been strengthening intellectual property protection to support innovation.
6. China has adjusted its trade policy to expand its global market share and enhance its competitiveness in the medical devices sector.

Such efforts seem to be paying off. In September 2014, the ASEAN Trade Promotion Association signed a strategic agreement with the China Medical Pharmaceutical Association with an intent to import $1 billion dollars' worth of quality-ensured medical equipment from China starting in 2015.[922]

Implications for the United States

With growing healthcare spending and increasing R&D funding, the Chinese medical devices market is attractive to US firms. In addition, China has been encouraging foreign businesses to invest in the medical equipment industry. In Shanghai and Beijing, medical device industrial bases focus on attracting foreign firms and investment to establish superior industrial clusters.[923] Yet the potential for greater market access may be constrained by a number of barriers in the Chinese market, such as regulatory procedures, reimbursement policies, and tariffs.[924]

The outcome of the dynamics between demand and competition in the medical devices industry is shown in Figure 25. China is not an immediate competitive threat to US medical devices manufacturers nor is it likely to compete with the United States in the short term due to the huge technology gap. Similar to the biopharmaceuticals industry, China has the potential to catch up with industry leaders in the long term, which makes the outcome less certain. In addition, many US firms are now competing directly with Chinese firms within the rural market segment, where price and practicality are the principal determinants.[925]

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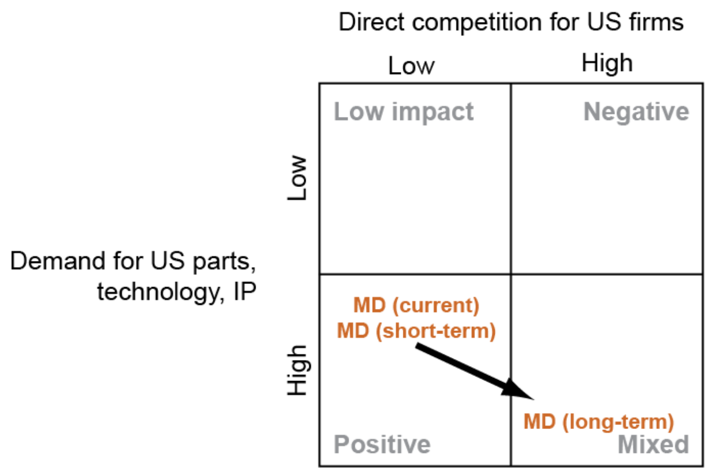
919 "2014 Blue Book of China's Medical Device Industry."
920 Ibid.
921 "商务部首次对医疗设备低价反倾销立案调查" [Ministry of Commerce Announced First Anti-Dumping Investigation on Medical Devices], 中国医疗器械行业网 [cn-ylqx.com], September 5, 2014, http://www.cn-ylqx.com/news/show.php?itemid=4931.
922 "价格优势被认可！国产医疗器械获东盟 10 亿美元订单" [Price Advantages Are Recognized; ASEAN Trade Promotion Association Made $1 Billion Order of Domestic Medical Devices], 生物谷 [*Bioon.com*], December 26, 2014, http://news.bioon.com/article/6664139.html.
923 Deloitte, "The Next Phase: Opportunities in China's Pharmaceuticals Market," (2011): 3−22, http://www2.deloitte.com/content/dam/Deloitte/ch/Documents/life-sciences-health-care/ch_Studie_Pharmaceutical_China_05052014.pdf.
924 Torsekar, "US Medical Devices and China's Market: Opportunities and Obstacles."
925 Ibid.

As US firms further tap into the Chinese market, they may localize their production to be close to customers and cut production and transportation costs, which has potential negative impacts for the US domestic labor force. For example, Varian Medical Systems, a leading radiation oncology treatment and software maker based in Palo Alto, California, has been building manufacturing facilities in China.[926]

Figure 25. Outcomes of Chinese investment in medical devices for US firms



Lessons from the Industry Case Studies

The eleven case studies presented in the preceding sections offer detailed and specific insights as to the dynamics and implications of near- and long-term developmental trends and the possible implications for the US economy. The major takeaway is that over the long term the mostly positive impacts that Chinese state plans currently have on US economic competitiveness will turn to either mixed or negative effects.

The determination of whether the impact on an industry is positive, negative, or a mixture of both is made by assessing the levels of direct competition for US firms from their Chinese counterpart, from barriers to competition put in place by Chinese policies and regulations, and also by changes in demand for US technology, components, and IP. A summary of these findings is presented in Table 16.

[926] "高端医疗设备市场低国产化 外资"三巨头"占八成" [Low Localization in High-End Medical Equipment Market, Foreign "Big Three" Account for Eighty Percent], 网易财经 [NetEase], March 28, 2015.

Table 16. The effect of Chinese S&T policies on US economic competitiveness in eleven sectors

Industry	Current	Short term (1–3 years)	Long term (10+ years)
Information and communications technology			
5G technology	positive	mixed—too early to tell	negative
Cloud computing	positive	mixed—with negative implications	negative
Global navigation satellite systems	positive	mixed—with negative implications	negative
Integrated circuits	mixed—with negative implications	mixed—with negative implications	negative
Manufacturing			
Additive manufacturing	positive	mixed—with positive implications	negative
Advanced robotics	limited positive	positive	mixed—with positive implications
Nanomaterials	limited negative	positive	mixed—too early to tell
Transportation			
Electric vehicles	negative	negative	mixed—with positive implications
High speed rail	limited positive	limited positive	limited positive
Medical and healthcare			
Biopharmaceuticals	positive	positive	mixed—with positive implications
Medical Devices	positive	positive	mixed—with positive implications

Current Impact

Six of the eleven industries examined currently have a positive impact on US economic competitiveness. With the exception of AM, these industries are concentrated in the ICT and medical/healthcare sectors. For the ICT industries, which are 5G technology, cloud computing, and GNSS, the large Chinese demand for US parts and components and technology is the positive draw for US companies and technology in China.

These industries though have faced challenges and setbacks in China because of the state S&T plans. China is investing heavily in 5G to become an early adopter of the technology and is promoting the development of the IoT and other initiatives associated with its Internet Plus strategy. In GNSS, China has rolled out requirements for certain vehicles to install dual-mode end terminals compatible with both GPS and Beidou. In cloud computing, domestic brands are being strongly supported and are specifically required in certain sectors because of national security reasons. Despite these plans, however, these Chinese industries are largely still in their infancy and far behind their US counterparts. This means that there is still strong and continuing Chinese demand for US parts, technology, and IP. The technological lead of US firms furthermore gives them a competitive advantage in the Chinese market. Overall, these strengths currently outweigh the negative consequences of China's state plans and policies.

The semiconductor industry differs from the other ICT case studies because government support for local companies that has become increasingly strong over the past few years is also coupled with other forms of protectionist practices. This has meant that the implications for US economic competitiveness is more mixed, with the trend becoming more negative. There are still positive effects, especially as US firms continue to supply a significant share of Chinese semiconductor demand. But the establishment of China's National Integrated Circuit Industry Investment Fund and its close ties to government decision makers and recent actions to leverage technology transfers from leading companies such as Qualcomm suggest that US firms face increasingly serious challenges in operating in the Chinese market.

The present positive dynamics for the biopharmaceutical and medical device industries is largely due to a recent major expansion in China's healthcare spending. The Chinese authorities have made both of these sectors of special state priority and US firms are able to benefit from an improving regulatory environment and growing demand for leading-edge healthcare products and drugs. Chinese biopharmaceutical and medical device companies are still unable to produce products at the technological frontier or meet market competition.

AM is the only manufacturing sector rated as currently positive. Two US companies, Stratasys and 3D Systems, presently dominate global market share, but Chinese companies are also growing quickly and proving their ability to compete in US and global markets. Current competition from Chinese firms is limited, as Chinese firms are mostly concentrated in manufacturing consumer 3D printers; however, state plans are strongly encouraging adoption of industrial 3D printing in order to upgrade China's traditional sectors. While this is expected to increase competition, it will also provide significant opportunities for US additive manufacturing firms since the Chinese AM industry is currently open to investment by US and foreign firms.

The advanced robotics, nanomaterials, and HSR sectors are rated as having limited impact at present from Chinese state plans. This is either because of the lack of strong US players, especially in the advanced robotics and HSR sectors, or low demand for US products and technology, which is the case for nanomaterials. In contrast to nanomaterials and HSR, which lean towards a limited negative impact, the impact in advanced robotics is assessed to be more positive because of the rapidly growing demand for foreign robotic technology in China.

The EV industry is the only sector determined to have a strong negative impact on US economic competitiveness at present. Multiple Chinese domestic plans and policies currently prevent US automakers from easily entering the Chinese market. These include a requirement that US automakers choosing to manufacture in China must first enter into a joint venture in which they hold a minority stake. Given the strong need to protect IP in this industry, few automakers are willing to agree to such a condition. Foreign firms also face extra costs compared to domestic firms in selling EVs in the China market and are not eligible for subsidies offered to domestic firms.

Short-term Impacts

Over the next one to three years, many changes are expected to occur in the impact that China's state S&T plans will have on US firms. One of the key developments is the expectation that China will continue to make significant technological advances during this period, many of which will be driven by state S&T policies. Sectors that could see major technological progress include 5G technology, AM, cloud computing, GNSS, and integrated circuits. These advances will likely result in increased competition between Chinese and US firms. In GNSS, for example, US firms likely will maintain a dominant presence in the Chinese market, but applications using China's Beidou navigation satellite system will begin to chip away at the Chinese GPS market share.

Analysis of the four ICT-related case studies indicates that they will turn from having a positive impact on US economic competitiveness to becoming more mixed with negative implications, although it is too early to tell for the 5G technology sector. China is making major technology advances in these four sectors because of strong government support, driven in large part by national security concerns. This has meant heavy state investment and policy support to nurture indigenous technology development capabilities. Indeed, the 5G technology, GNSS, and integrated circuits sectors are dominated by large SOEs that receive heavy state-backed financing. Cloud computing also receives significant financing from the Chinese government, but is dominated by privately-owned companies such as Baidu, Alibaba, and Tencent. Due to their vulnerability to cyber and other threats, each of these industries is heavily regulated, but in a way that strongly advantages local Chinese companies. Due to national security concerns, The Chinese authorities are also more likely to proactively discriminate against foreign firms in these areas and less likely to address perceived discriminatory policies in response to complaints from foreign firms or governments about Chinese requirements that the technology being sold must be "secure and controllable." Prominent discriminatory policies include indigenous innovation and China's IDAR strategy, whereby China seeks to "introduce, digest, adapt, and re-innovate" technology from foreign industry and technological leaders.

AM is also expected to turn to a mixed pattern of positive and negative impacts over the next few years, although the reasons why differ from the ICT sector. The shift in competition in the AM sector will derive more from Chinese companies upgrading their technology through largely market-driven methods. These advances will most likely be concentrated in the consumer printer business. Chinese research teams and companies are also expected to make progress in industrial applications of 3D printing, especially in the aerospace sector, but these investments will likely not be apparent until the longer term.

The biopharmaceuticals and medical devices industries are expected to continue to offer profitable investment opportunities for US companies as China's healthcare market expands, with overall positive implications for US economic competitiveness. Chinese firms in these healthcare industries will still likely lag significantly behind US firms in terms of technology, and US firms most likely will still be able to take advantage of government incentives such as public R&D funding as they partner with domestic firms.

Advanced robotics and nanomaterials are also projected to become more positive for US economic interests in the short term. While the United States is not a current leader in advanced robotics or nanomaterials, a growing Chinese market will also provide US firms with opportunities to expand their presence in China to increase production and supply. In the current to short term, the strongest competitors for US firms will be from industry leaders in Japan, Germany, and other developed countries, but not China.

Long-term Impacts

Assessing long-term impacts for US economic competitiveness is a more speculative exercise, but the IC sector is expected to be the most negatively affected over the next 5–10 years. This is because the national security imperatives driving China's demands to regulate foreign competition and promote domestic champions will continue to exert powerful influences on the development of this sector. The Chinese government hopes that high-end, locally-made chips will become available during this period to supply sensitive and strategic industries such as 5G and GNSS. Some IC industry experts draw parallels between the unabashed transfers of technology from HSR global leaders to Chinese firms that led to the takeoff of China's HSR dominance and activities currently being witnessed in China's treatment of IC suppliers and IP holders.[927] AM is also likely to be negatively impacted in the long-term due to strong Chinese competition with US industry players.

In advanced robotics, biopharmaceuticals, medical devices, EVs, and nanomaterials, the impacts on US firms from China's advances in domestic technology will be mixed. In each of these sectors, US and Chinese firms are expected to advance technologically, and they will compete in each other's markets. While the Chinese market will continue to grow, US companies are likely to be crowded out by Chinese domestic companies as the Chinese government seeks to incubate national champions and establish dominant local players. Consequently, US companies may receive a smaller share of the Chinese market in the long term. There is reason to believe, however, that the mixed overall impact for these sectors will lean toward a more positive direction for US firms because they will continue to have a technological edge over their Chinese counterparts. Moreover, the Chinese authorities are less inclined to interfere in these sectors because of the lack of pressing national security rationales, so these markets will be more open.

For EVs, this shift toward a mixed impact in the long term is due to a hoped-for relaxation of China's current strict protectionism of local automakers. For early emerging industries like nanomaterials, there is too much uncertainty to tell whether this sector will be negative or positive for US interests. HSR is likely to continue to have limited positive ramifications for US economic competitiveness.

These eleven case studies were selected because they represent the high-technology sectors that are most likely to be at the leading edge in the intensifying US–China race for global technological competitiveness over the long term. The themes and trends that are driving their development and impact are reflective of the overall evolution in China's science, technology, and industrial development and, consequently, hold major implications for the United States and its economic competitiveness.

Examining US Labor Market Impacts from China's Technology Development

In addition to varying levels of increased competition for US firms, China's rise in S&T capacity and accompanying escalation of state S&T-directed policies also have implications for the US labor market.[928] In the following section, the focus of attention will turn to examining the possible

[927] Interview with semiconductor industry representative, January 14, 2016.

[928] This section benefited substantially from the contributions of Barry Naughton at UC San Diego.

impact of the development of the case studies of the high-technology industries covered in this report on the US labor market. While making credible projections of this impact is extremely difficult, a range of outcomes that can reasonably be anticipated is analyzed, leading to the conclusion that among the case studies examined, there is unlikely to be a large impact on manufacturing employment. Still, many other factors need to be considered, such as Chinese investment in the United States, impacts of China's high-tech rise on traditional sectors, the movement of supply chains, and competition for high-level, executive talent.

The Current State of the US and Chinese High-Technology Manufacturing Industries

In the 2016 edition of its bi-annual *Science and Engineering Indicators* report (S&EI), the US National Science Board provides a snapshot of the current state of the US and Chinese high technology manufacturing industries and their places in the global technology order.[929] The once-dominant position enjoyed by the United States in global high-tech manufacturing has been steadily eroded by China's rise. The US share of world high-tech manufacturing has fallen from 33 percent over the past decade to 29 percent in 2011, which the S&EI report attributed "largely due to much faster growth in China."[930] In terms of the employment impact, US high-tech manufacturing jobs have fallen from 2 million in 2008 to 1.8 million in 2014 despite a recovery in output, which the S&EI report argues, "reflects the relocation of production to China and other countries, as well as the rapid productivity growth of US [high-tech] manufacturing industries."[931]

China's share of global high-technology manufacturing has grown over the last decade from 8 percent to 27 percent. The key factors accounting for China's success include state policies and subsidies to encourage multinational companies to invest in China, low wages, adequate infrastructure, and the global scale of Chinese manufacturing plants.[932]

Another feature of the US–China high-tech manufacturing relationship, and especially relevant in assessing the longer-term bilateral competition, is that these two countries occupy different places in the global high-tech manufacturing hierarchy. The United States dominates in aircraft production, with a 52 percent global share in 2014, as well as in testing, measuring, and control instruments with a 42 percent share in 2014. China leads the way in the ICT (computers, communications, and semiconductors) industry with a 39 percent share in 2014.[933] Although China is investing heavily in the development of its commercial aircraft industry, the likelihood that it can break the duopoly that the United States (led by Boeing) and Western Europe (led by Airbus) over the next 10–20 years is extremely low given the large technological gap that the Chinese industry faces, the long periods required for R&D, and the exacting safety and environmental standards that have to be met in global markets.[934] China also lags the United States and Europe technologically and by market share by a wide margin in the global general testing and measurement sector and is

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[929] National Science Board, *2016 Science & Engineering Indicators,* NSB-2016-1, January 2016, chap. 6.
[930] Ibid., chap. 6, 32.
[931] Ibid, chap. 6, 44.
[932] Ibid.
[933] Ibid, chap. 6, 43–44.
[934] Keith Crane et al., *The Effectiveness of China's Industrial Policies in Commercial Aviation Manufacturing* (Santa Monica, CA: RAND, 2014).

unlikely to challenge for leadership anytime soon.[935] Overall, the S&EI report concludes that Chinese high-tech manufacturing "continues to be limited to lower value-added activities, such as final assembly."[936]

Consequently, China's dramatic rise as a global high-technology manufacturing powerhouse and its impact on the United States may be reaching the limits of its high-octane growth unless it is able to make major inroads into new and emerging high-technology areas.

Why Labor Market Impacts Are Impossible to Project

In assessing the possible impact of Chinese state S&T and industrial plans on US employment and production, the first point that needs emphasis is that it is extremely difficult to make credible projections. This conclusion comes from numerous interviews conducted with leading experts specializing in China–US trade, labor economics, Chinese economics, and S&T policy.[937]

Nonetheless, this section examines the possible magnitude of employment impacts within a large range. This exercise can be useful for policymakers. However, these should not be considered projections, but instead a form of sensitivity analysis. Moreover, labor market impacts are not necessarily the most important impact on the United States. As discussed elsewhere in this report, other impacts, including technology leadership, corporate profits, and national security, are equally important.

Labor market impacts are impossible to project for three main reasons:

1. **The sectors examined in the case studies are intrinsically new, with substantial technological and market uncertainty.** It is certainly possible for economists to project many economic magnitudes with reasonable confidence, but these projections rely on the gradual growth of input availability, the laws of demand, and reasonable assumptions about aggregate productivity growth. None of these assumptions hold in the cases under review. Many of the markets under discussion are fundamentally new, and the pace at which new products will substitute for old products (if at all) is not known. These uncertainties make projections only slightly better than guesses.
2. **Labor market outcomes depend on the comparative and competitive development of industrial sectors in the United States and China**. In other words, projections depend on informed guesses about the *speed* with which entrepreneurs in both countries actually bring robust, low-cost solutions to the marketplace. This report brings together reasonable judgments about the progress China has and has not made in developing targeted industries, but projection of labor market impacts in the United States requires an additional set of judgments about the progress US companies are making. These judgments require insider knowledge of

[935] *2016 Science and Engineering Indicators,* chap. 6, 43−44.
[936] Ibid., chap. 6, 44.
[937] Interviews were conducted with more than a dozen US experts from the Council on Foreign Relations, Economic Policy Institute, Information Technology and Innovation Foundation, National Telecommunications and Information Administration, Finnegan LLP, Robotics Industry Association, Science and Technology Policy Institute, two semiconductor organizations, an international economic policy advisory firm, Massachusetts Institute of Technology, UC San Diego, and Chinese Academy of Sciences. Industry specializations included semiconductors, biotechnology, additive manufacturing, advanced manufacturing, robotics, and telecommunications.

many different companies and are simply not in the public domain. Informed guesses about relative progress in these areas are intrinsically difficult.

3. **The economic impact of comparative industrial development depends on China's overall trade and market reform policies.** The assumptions used below on the impact of Chinese imports are formulated using a baseline period in which China's trade surplus with the United States increased at a rapid and sustained rate (19 percent per year between 1991 and 2007). China's global trade surplus increased dramatically in this period as well. Since the assumptions incorporate this type of rapid increase in the US deficit, they represent a "worst case" range in this respect. China's surplus with the United States is unlikely to increase as rapidly in the future as it did in the 2000–2007 period. To be sure, it cannot be assumed that the US deficit with China will decline—from 2007 to 2015 the deficit continued to increase by 4.4 percent per year.

For these reasons, the following calculations cannot be considered projections. Rather, they represent a type of sensitivity analysis: in other words, given plausible assumptions, what is the range of outcomes that can reasonably be anticipated. The sensitivity analysis confirms the argument made elsewhere in this report that labor market impacts are, through the medium run, not the most important impact on the United States of China's industrial innovation policies.

To a certain extent, this result is inevitable. Manufacturing employment as a share of total US nonfarm employment has declined steadily since World War II, and is currently 9 percent of total employment. This implies that even quite large impacts on manufacturing employment are relatively small in the context of total US employment. As the following section demonstrates, the high-tech sectors under review are unlikely to have a large impact on manufacturing employment.

Examining the High-Tech Sectors

The following considers Chinese impact on the US labor market through the trade channel. In certain sectors, one might anticipate relatively large changes in net imports. However, the situation is quite different in different sectors. Three sectors where Chinese intervention will have minimal direct impact on traded goods can be discarded immediately: cloud computing, GNSS, and nanomaterials. Each of these has significant impacts in other areas, and they may contribute to overall increases in industrial productivity, thereby affecting trade balances. However, those indirect effects are impossible to estimate.

For the remaining eight sectors, potential outcomes vary greatly. The situation is exemplified by trade in telecommunications items embodying 5G technology. The United States currently runs a $61.8 billion deficit with China in telecommunications equipment. This is primarily because virtually all telecommunications consumer goods are assembled in China. Even the most successful Chinese initiative in 5G telecommunications is unlikely to change this number much, because essentially all US smart phones already come from China. Rather, the benefit to China of success in this area would come in improved royalty rates and return on design and marketing, neither of which appears in trade accounts. Consequently, estimating the impact of changing trade relations in this sector mainly reflects plausible guesses about the unit price and growth in the number of units produced in locations other than China.

The telecommunications sector is also an important exception to a generalization that covers the other sectors. Precisely because these are high-technology sectors, the absolute value of China–US trade in these sectors is currently relatively small. That is, the enormous US deficit with China is primarily composed of low-technology, labor-intensive manufactures and assembly processes. Of the staggering $366 billion bilateral deficit with China in 2015, about half comes from traditional labor-intensive manufacturing (garments, shoes, toys) and the other half comes predominantly from electronics assembly (including phones and computers).

This has two important implications. First, in *none* of the sectors under review does China have a "natural" competitive advantage based on cheap labor or existing skills. As a result, in none of these sectors does China today have a substantial position as an exporter to the US market (with the sole, but important, exception of telephone equipment). Of course, China may be able to create a sustainable competitive advantage by its massive investment in these sectors and through the protection it gives to its domestic firms in these sectors. Quantitatively speaking, however, the capacity to export to the United States will need to be built up from initially extremely low levels. This was never the case with the labor-intensive manufactures on which the current deficit is based: these were already established in China's neighbors (Hong Kong, Taiwan, and South Korea) and were easily adapted to take advantage of China's low labor costs.

Second, domestic sectors and domestic demand in China are poised to grow rapidly as well. That means there is substantial potential opportunity for US businesses who already have competitive advantages in these areas. To be sure, the entire purpose of Chinese interventions in these sectors are precisely to deny US businesses these opportunities and seize this market opportunity for Chinese firms. We cannot neglect the possibility that Chinese policymakers will erect barriers to US exports to their market, either explicitly, in hidden forms, or simply through the operation of the massive subsidization of Chinese producers that is incorporated in their technology policies. Such efforts will not necessarily be successful, and to the extent that they are not successful, US firms are poised to expand exports.

As a result, when one considers the US labor market impacts of Chinese policies, one must also consider the possibility that weak, inconsistent, or ineffective implementation of these policies will lead to continuing opportunity for US firms; or even consider the possibility that successful implementation of Chinese policies will still leave room for expanding US exports in rapidly growing markets.

To capture the range of possibilities that emerge from these considerations, Table 17 shows a range of estimates for shifts in net US imports from China (that is, the bilateral trade deficit), in billions of dollars, associated with each of the eight sectors with significant potential to affect imports. In all eight cases, a major increase in Chinese market share would add significantly to US imports. Four of these sectors are associated with extremely large US markets: telecommunications equipment; electric vehicles; biopharmaceuticals; and medical instruments. In each of these four cases, a plausible increase in Chinese imports in the wake of a successful plan of technological development could increase US imports by more than $10 billion. Combining these "worst case" scenarios with similar, but quantitatively less significant, outcomes in the other four sectors could leave the United States with a $55 billion increase in net imports from China by 2020.

Table 17. Increase in US net exports: Sensitivity analysis ($ billions)

	2017		2020	
	Low estimate	**High estimate**	**Low estimate**	**High estimate**
Sector				
5G	−6.2	6.2	−12.4	12.4
Integrated circuits				
Integrated circuits	−0.5	0	0	2.5
Machinery	−0.4	0	−0.8	0.7
Additive manufacturing	0	0.2	−0.2	1.2
Robotics	−0.1	0	−0.4	0.2
Electric vehicles	−0.1	0.5	−1.0	10.0
High speed rail	0	0.1	0	0.5
Biopharmaceuticals				
US exports	−9.0	0	−15.0	0
US imports	0	7.5	0	17.5
Medical devices				
US exports	−2.7	0	−5.0	−2.0
US imports	0	0.5	0	12.0
Totals	−19.0	15.0	−34.8	55.0

Note: Estimates based on sector-by-sector assumptions, provided in Appendix C.

However, this scenario of maximum increase in US market penetration must be put into two important contexts. First, the $55 billion figure represents the outcome of successful mercantilist policies by the Chinese government in which all the policies are successful simultaneously. While this outcome cannot be excluded completely, it is extremely unlikely. Second, and more important, Chinese penetration of the US market must be weighed against potential US penetration of the Chinese market. This potential is especially significant in the case of biopharmaceuticals and medical instruments. In addition, it is possible that changes in the telecommunications industry (plummeting unit prices for smart phones plus deceleration in unit price) will cause a large reduction in the value of US imports of telecommunications equipment from China, even in the unlikely case that China dominates the global 5G standard. If all these plausible positive market outcomes are realized (and none of the negative possibilities), then US net imports from China will decline by almost $35 billion by 2020.

To be sure, it is very unlikely that either of these extreme values will be realized. Far more likely is a mix of outcomes, including some dramatic market successes in the United States by Chinese firms, and a few dramatic successes in the Chinese market by US firms. In such an outcome, the overall impact on US net imports from China is likely to be close to zero. We must emphasize that we are not projecting a zero increase in US net imports from China. Rather, our analysis shows that there is a range of plausible outcomes, and that this range contains the possibility of a zero increase as a highly plausible result. However, anything up to the extremes is also plausible, so it is necessary to examine the labor force implications of the extremes.

Outcomes and Impact on the US Labor Market

The methodology developed by David Autor, David Dorn, and Gordon Hanson provides a useful way to investigate potential labor market outcomes.[938] This important study documented the very large loss of US jobs as Chinese import penetration increased from almost nothing to more than 10 percent of the US manufactured goods market over the 20 years from 1991 to 2011. Using local labor markets (commuting zones), and differentiating them by their exposure to actual Chinese imports, Autor et al. take into account both the initial impact of the import shock and the local labor market adjustments to this shock. While taking into account these adjustments should, in theory, reduce the magnitude of the shock since workers can shift to other jobs, they find large effects overall. The Chinese import shock reduced manufacturing employment as a share of population by 1.78 percent, or 2−2.4 million workers.[939] Note that this shock includes the fact that the US deficit with China (and overall) expanded rapidly during this period. The method of Autor, Dorn, and Hanson is calibrated to imports per worker, which enables us to use their estimated results with our range of plausible outcomes for the change in net imports. The results of this episode are shown in Table 18.

Autor et al. calculate that for every increase in net manufactured imports from China, over a decade-long period, the share of manufacturing employment in the working-age population decreased by 0.6 percentage points. Applying this elasticity to the range of plausible trade outcomes, we find (Table 18, Row 4) that by 2020, in the adverse (high) estimate of increased net imports, manufacturing employment would fall by 431,600 workers. In the most favorable (low) estimate of increased net imports, manufacturing employment would increase by 273,100, reflecting the increase in net high-tech imports to the Chinese market. The actual variation in employment would probably be somewhat less than this, because these high-technology sectors use relatively less labor per unit of output than existing imports from China (on which the estimation is based). On the other hand, those jobs are of a higher quality, involving more skill and higher pay.

While the high-technology economy is of vital importance for the United States and China in their efforts to enhance their economic competitiveness and national security, it features less prominently in the debate about how China's rise impacts US production and jobs. The consensus among US experts interviewed for this report was that the primary source of concern for the US economy continues to be in traditional industrial sectors such as steel, aluminum, and, more recently, auto parts.[940]

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[938] David H. Autor, David Dorn, and Gordon H. Hanson, "The China Syndrome: Local Labor Market Effects of Import Competition in the United States," *American Economic Review* 103, No. 6 (2013): 2121−68. See also David H. Autor, David Dorn, and Gordon H. Hanson, "The China Shock: Learning from Labor Market Adjustment to Large Changes in Trade," NBER Working Paper 21906, January 2016, http://www.nber.org/papers/w21906.pdf, and Daron Acemoglu, David Autor, David Dorn, Gordon Hanson, and Brendan Price, "Import Competition and the Great US Employment Sag of the 2000s," *Journal of Labor Economics* 34, No. S1, Part 2, January 2016.

[939] By contrast, other estimates implicitly assume that labor markets do not adjust at all to import shocks; that is, the reduction in employment equals the labor content of the (increased) trade deficit. This produces a higher number which is, however, indefensible theoretically. For example, Robert E. Scott and Will Kimball ("China Trade, Outsourcing, and Jobs," *EPI Briefing Paper 385*, December 11, 2014) follow this methodology and come up with an estimate of 3.2 million jobs lost. Of these, 40 percent were considered to have been lost in computer and electronics products.

[940] Author interviews with Edward Alden, senior fellow at the Council on Foreign Relations, and with Robert E. Scott, senior economist and director of Trade and Manufacturing Policy Research at Economic Policy Institute, Washington, D.C., January 13, 2016.

Table 18. Labor market impact: Sensitivity analysis

	2017		2020	
	Low estimate	**High estimate**	**Low estimate**	**High estimate**
1. Increase in net imports	19.0	15.0	-34.8	55.0
2. Increased net imports per worker ($US 1,000)	0.129	0.101	0.223	0.353
3. Percentage point change in ratio of manufacturing employment/population	0.08%	-0.06%	0.13%	-0.21%
4. Change in manufacturing employment (thousands)	153.8	121.1	273.1	431.6

Emerging research has begun to offer implications for US high-tech industries from China's push for technological advancement, but these are still minor compared to other implications likely to result from China's growing S&T plans. Notwithstanding this observation, a number of critical considerations give further context to the dynamics involved in China's rise in S&T capacity and its relation to the US labor market. Four of these are detailed here.

First, as noted throughout the case studies, the primary impacts from China's state plans will occur in China's domestic market and not in the United States.[941] This continues to be the message of reports and surveys documenting the experiences of US companies doing business in China.[942] This does not mean that local effects on the US workforce will not occur. EPI analyst Robert Scott argues that US imports from China are moving up the value-added chain and include higher amounts of advanced technology. He warns that this creates "serious implications for certain kinds of high-skill, high-wage jobs once thought to be the hallmark of the US economy."[943] This is likely to have some impact, but China's role in most current high-tech exports to the United States continues to be that of an assembler. Consequently, while the value added of imports from China is rising, the threat to US high-tech jobs is most likely much less than experienced in other labor-intensive sectors where China's low wages and abundant workforce give it a natural comparative advantage. As Autor, Dorn, and Hanson conclude, "the great China trade experiment may soon be over, if it is not already … Its comparative advantage in the future will likely be less about its labor abundance and random initial industry prowess, and more about the endogenous responses of business and government to the global economic environment."[944]

Meanwhile, China's FDI and M&A of US companies is also not likely to have a significant positive impact on boosting US production and jobs. Much attention has been given to Chinese investment in the United States, but the magnitude of investment from China to the United States is relatively small among China's global investment portfolio. The United States accounted for only 3.3 percent of total Chinese overseas investment by the end of 2013. This number rises to 7.7

[941] Interview with Edward Alden.

[942] For example, the most recent China Business Climate Survey Report by the American Chamber of Commerce in China shows that policies and regulations outlined for supporting its domestic and indigenous growth in China continue to be the largest concern for US companies, especially those in the high-tech industry. AmCham China, "2016 China Business Climate Survey Report."

[943] Robert E. Scott, "The China Toll: Growing US Trade Deficit with China Cost More than 2.7 Million Jobs Between 2001 and 2011, with Job Losses in Every State," Economic Policy Institute, August 23, 2012, http://www.epi.org/publication/bp345-china-growing-trade-deficit-cost/.

[944] Autor, Dorn, and Hanson, "The China Shock."

percent if Chinese FDI in Hong Kong is excluded, but is still small compared to the 19 percent global average of FDI directed to the United States.[945] Nonetheless, the volume and size of Chinese FDI into the United States has been growing strongly over the past few years. In 2014, total Chinese investment in the United States is estimated to have totaled $12 billion, which would account for around 10 percent of total FDI that the United States received that year.[946] By comparison, in 2009 China accounted for only 0.1 percent of total inward FDI stock to United States.[947]

The effect from China's growth of US-bound FDI on US jobs is not negligible, but is much smaller when compared to job losses attributed to trade with China. The Rhodium Group estimates that 80,000 jobs in the United States are currently being supported by Chinese-affiliated companies and predicts that by 2020 this number could rise to between 200,000 and 400,000.[948] High-tech investment from China is playing an increasingly large role in creating and supporting these jobs, with an estimated 25,000 full-time jobs in the United States resulting from this investment. Compared to traditional sectors, Chinese FDI in high-tech sectors is more likely to include greenfield projects, where it is common for R&D facilities, learning centers, manufacturing and distribution facilities, and headquarters to be constructed. These projects are regarded as more beneficial in terms of job creation.[949] The Rhodium Group estimated that there were around 6,000 high-tech jobs created through greenfield projects in 2014, and 19,000 high-tech jobs in the United States are supported by Chinese firms through acquisitions.[950]

Second, the development and application of technologies in high-tech sectors may have growing indirect implications for traditional sectors. Steel, aluminum, auto parts, and other traditional industries continue to be the sectors most affected by China's growth and policies, while high-tech and emerging sectors have had a much more limited effect.[951] For instance, Chinese manufacturers are increasingly replacing workers with automation as a way to maintain cost advantage. As this strategy expands, US manufacturing sectors, such as the automotive industry, can be expected to continue outsourcing production to China, which will negatively affect US domestic production and jobs.

Third, the movement and evolution of supply chains may also result in negative implications for US jobs and production.[952] China's emergence as a hub of global supply chains has meant a large-scale shift of production from the United States and other countries, especially in the Asia-Pacific

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945 Much of China's investment in Hong Kong is likely due to it being a transit location and not the final destination of FDI. See David Dollar, "United States-China Two-way Direct Investment: Opportunities and Challenges," Brookings Institution, January 2015, http://www.brookings.edu/~/media/research/files/papers/2015/02/23-us-china-two-way-direct-investment-dollar/us-china-two-way-direct-investment-dollar.pdf.
946 Thilo Hanemann and Cassie Gao, "Chinese FDI in the United States: Q4 and Full Year 2014 Update," January 15, 2015, http://rhg.com/notes/chinese-fdi-in-the-united-states-q4-and-full-year-2014-update.
947 Daniel H. Rosen and Thilo Hanemann, "An American Open Door? Maximizing the Benefits of Chinese Foreign Direct Investment," Asia Society and Woodrow Wilson International Center for Scholars, May 2011, http://asiasociety.org/files/pdf/AnAmericanOpenDoor_FINAL.pdf.
948 Rhodium Group, "New Neighbors: Chinese Investment in the United States by Congressional District," 7−8.
949 Thilo Hanemann and Daniel H. Rosen, "High Tech: The Next Wave of Chinese Investment in America," Asia Society, April 2014, 22, http://asiasociety.org/files/China_Hi_Tech_Report.pdf.
950 Hanemann and Rosen, "High Tech: The Next Wave of Chinese Investment in America," 56.
951 Author interviews with Edward Alden and Robert E. Scott.
952 Author interview with Edward Alden.

region, to China over the past two decades. This has been especially pronounced in the ICT sector, where China has overtaken the United States. In computer equipment, much of the global supply chain has relocated to China. In 2000, Chinese exports of computer equipment to the United States were only 12 percent of total US imports in this category, while Japan was first with 19.6 percent. By 2014, China's share had leaped to 64 percent, while Japan's computer exports to the United States had dropped to 3.4 percent.[953] In flat-panel displays (FPD), another ICT subsector, China's manufacturing capacity is expected to grow 40 percent per year between 2010 and 2018, which would see its share of global capacity jump from 4 percent to 35 percent. With this surge in growth, BOE Technology Group, a relatively small Chinese FPD producer, is predicted to become the third-largest global producer of FPDs by 2018.[954] Much of this growth is driven by increasing local demand combined with government incentives to manufacture in China through tariffs on imports of FPD cells—a sort of import substitution intended to bolster China's domestic suppliers.[955] The United States no longer has any production capacity for FPDs.[956]

Competition for supply chains will likely also be fierce in other emerging high-tech sectors, including the industries profiled in this report. In cloud computing, for example, the Trans-Pacific Partnership (TPP) dictates that a country cannot mandate that storage centers be located domestically. China is not a TPP signatory and does not have laws violating this policy. However, in April 2015, the US Chamber of Commerce complained of policies enacted by China that essentially demanded the creation of local data centers to protect data security because of national security concerns. According to the American Chamber of Commerce in China, Chinese laws prohibit banks from storing personal financial information outside of China or allowing data to be removed from China if it contains state secrets.[957] If the language of this law remains unadjusted, this could incentivize US and other foreign companies to locate cloud computing facilities and supply chains in China in order to maintain a market presence there.

Finally, an increasingly important battleground is the competition for top talent and executive leadership in high-tech sectors. China is suffering from an acute shortage of high-level technical and managerial talent at home.[958] To tackle this problem, the Chinese authorities are actively reaching out to the global talent pool to attract talent through plans such as the Thousand Talents Plan and also through strategic acquisitions of foreign companies with cutting-edge expertise. For example, when Chinese semiconductor firms first began to acquire US businesses, their initial

[953] Wayne M. Morrison, "China-U.S. Trade Issues," Congressional Research Service, December 15, 2015, 9−10.
[954] Charles Annis, "China to Dominate Flat Panel Display Manufacturing by 2018, IHS Says," IHS Technology, November 5, 2015, https://technology.ihs.com/551480/china-to-dominate-flat-panel-display-manufacturing-by-2018-ihs-says.
[955] "China FPD Market Expands to Meet Local Demand, Global Markets," SEMI, December 7, 2010, http://www.semi.org/en/IndustrySegments/FPD/CTR_042055?id=sgueu1210t.
[956] Gary P. Pisano and Willy C. Shih, *Producing Prosperity: Why America Needs a Manufacturing Renaissance* (Cambridge, MA: Harvard Business Review Press, 2012), 12.
[957] Michael Kan, "US Business Group Urges China to Loosen Data-Storage Policies," *Computer World*, April 14, 2015, http://www.computerworld.com/article/2909741/us-business-group-urges-china-to-loosen-datastorage-policies.html.
[958] Rhodium Group, "New Neighbors: Chinese Investment in the United States by Congressional District," Report by National Committee on US-China Relations and Rhodium Group, May 2015, http://rhg.com/wp-content/uploads/2015/06/RHG_NewNeighbors.pdf, 60.

targets were companies that had Chinese executive leadership. Acquiring technology was important to these companies but so was accessing talent that could be easily integrated into existing corporate structures and culture.[959] Rather than transferring jobs back to China, mainland Chinese acquisitions of US companies are now often made with a strong intent to gain access to technological know-how and a "well-educated, international, and diverse workforce."[960] In the case of Lenovo's acquisition of IBM's PC division, for example, it was able to retain most of its top executives in the new company.[961]

Implications of Energy Policy for the United States and Global Communities

Many Chinese companies are actively seeking opportunities to become global players in energy, which largely holds positive implications for the United States. These implications range from commercial opportunities to opportunities for international and environmental engagement. There are areas where China's external involvement can provide new products and develop new markets. China's policy toward international players is not without concomitant risks for the United States, however, the most obvious of which is China's indigenous innovation effort but also extending to competition and safety issues.

Looking Overseas

The major concern with China's international energy activity in recent years has been its investment in foreign oil plays. This is less likely to be the case in the near term. Not only does a low oil price mean there are relatively few interesting new finds, but China's oil executives are doing business in the midst of a far-reaching anti-corruption and political crackdown. Large scale oil investments are very expensive and risky, and officials are now afraid that a bad call might be perceived as corruption.[962]

As a result, while outward oil investment averaged $21 billion between 2010 and 2013, it was less than $10 billion in 2014.[963] Concerns about Chinese involvement in failed states, at least in the oil industry, are now much lower than in the mid-2000s. The major international Chinese interactions will be primarily related to investment in gas projects in Russia and Central Asia. These projects face market challenges at present, but more transactions with these regions are likely to take place over the longer term. China and Brazil also have an active partnership in developing offshore oil, and this partnership will be a priority for the Chinese majors.[964] More generally, China's ever-rising demand for oil and gas ensures that it will be interested and active in the Middle East and

[959] Author interview with semiconductor industry representative, January 16, 2016.
[960] Rhodium Group, "New Neighbors: Chinese Investment in the United States by Congressional District," 60.
[961] Tim Bajarin, "10 Years Later, Looking Back at the IBM-Lenovo PC Deal," *PC Magazine*, May 4, 2015, http://www.pcmag.com/article2/0,2817,2483557,00.asp.
[962] Author interview with Erica Downs.
[963] Ibid.
[964] Amrutha Gayathri, "Brazil Sells Giant Libra Oil Field Rights to Consortium Including Petrobras, Shell, Total, CNOOC, and CNPC," *International Business Times*, October 22, 2013, http://www.ibtimes.com/brazil-sells-giant-libra-oil-field-rights-consortium-including-petrobras-shell-total-1435158; "Closer Financial Ties Lift China-Brazil Oil Cooperation to New Level," Xinhua, June 20, 2015, http://news.xinhuanet.com/english/2015-06/20/c_134343534.htm.

also in maintaining open access to sea lanes of commerce for petroleum shipments from this region. China's assertion of territorial claims in the South and East China Seas can also be expected to encourage petroleum exploration.

The larger Chinese effort most recently is not focused on resource acquisition, but on infrastructure sales. Some of these actual and potential transactions are to the same states that have proven controversial in the past. For example, Sudan is among the countries that China would like as a nuclear power customer.[965] Nuclear sales abroad may well raise nonproliferation concerns. Friction with dam opponents for the many hydro projects connected to the One Belt, One Road and other initiatives is likely be more common as well.[966]

Conversely, Chinese sales are also likely to help other countries provide cheaper and possibly cleaner energy to their citizens. The standard Chinese coal-fired power plant sold today can be equipped with state-of-the-art pollution abatement equipment. China is also a competitive producer of renewable energy options.

Many Chinese companies are interested in becoming global players, including by investing in and even purchasing US companies. There has been active Chinese investment ranging from shale gas to solar to wind. Many of these are simply investments without a technology component, such as CNOOC's minority interest in US shale gas company Chesapeake, but company purchases can also be a way to acquire technology and expertise.[967]

The solar and wind purchases are much more complex, involving real learning about the US market and active involvement with US firms and staff. For example, Goldwind, a major Chinese wind power manufacturer, has a US subsidiary, with major projects in collaboration with US engineering, construction, and certification firms as well as investors.[968] Chinese solar firm Hanenergy acquired US solar-thin film manufacturer MiaSolé, not only gaining access to its technology, but further investing in the firm's US-based R&D.[969]

Opportunities for the United States

Energy tends to be an area where home market advantage is important. The sheer size of the Chinese market gives Chinese companies room to develop and establish lucrative domestic bastions. However, there are a number of areas where there are economic, political, and environmental opportunities for US companies.

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[965] Sudan and China signed a deal for a research reactor in 2012. Kuwait News Agency, December 23, 2012, http://www.kuna.net.kw/ArticleDetails.aspx?id=2283263&language=en.

[966] See, for example, the advocacy group International Rivers' campaign against Chinese dams.

[967] "CNOOC Buys Shale in China's Biggest US Oil Deal," *Bloomberg News*, October 11, 2010, http://www.bloomberg.com/news/articles/2010-10-11/cnooc-unit-to-pay-1-08-billion-in-cash-for-stake-in-gas-project.

[968] Author interview with Joanna Lewis; Mark Del Franco, "North American Windpower: With Illinois Project, Goldwind Signals Its Intentions" North America Wind and Power, April 2013, http://www.nawindpower.com/issues/NAW1304/FEAT_02_With_Illinois.html.

[969] Melanie Hart, "Mapping Chinese Direct Investment in the US Energy Economy: Current Patterns and Future Opportunities," Center for American Progress, July 30, 2015, https://www.americanprogress.org/issues/green/report/2015/07/30/118372/current-patterns-and-future-opportunities/.

Commercial Opportunities

There are numerous areas of commercial opportunity as China modernizes and upgrades its energy system and makes it cleaner and safer.

- **Safety and monitoring**: New environmental and safety standards mean that tracking and testing are ever more important. This is already an area where US and other international companies, such as Thermo Scientific and Honeywell, are active, and Chinese interest in these types of products and services can be expected to increase. There is real demand for all types of current source specific and ambient pollution monitoring devices, and for better safety monitoring at all types of energy facilities from coal mines to nuclear power stations. There will be demand for new technologies as well. For example, given the Chinese policy approach of assigning carbon and pollution targets by jurisdiction, monitoring devices that are able to track pollutants by source signature at a reasonable price would be very attractive.
- **Gas turbines:** China still does not have all the technologies for wholly-domestically produced gas power generation. It imports turbines from both the United States and Europe. While the gas market is weak for now, interest and demand will grow over the longer term, and this will come with Chinese requirements for its firms to produce their own IP. This issue is particularly sensitive because some turbine components are subject to US export control rules, thus making it impossible for US firms to make technology transfer deals.
- **Electricity storage:** The Chinese energy industry has considerable need for electricity storage technology, from vehicles to large-scale renewables to microgrids. There have been a number of battery collaborations, and high demand can be expected if the United States makes any technical breakthroughs.
- **Energy efficiency:** A number of US companies, including Honeywell and Johnson Controls, have successfully sold efficiency improvements to various industries. There continues to be a lucrative market for solutions to industrial efficiency and pollution problems. Whether the same market will exist for energy-efficient buildings is an open question. Many US companies hope so, but the Chinese construction business is generally driven by low cost dynamics.
- **Power grid management:** Issues such as how to manage fluctuations from renewables continue to plague the grid, leading to opportunities for US companies with effective solutions.
- **Oil and gas:** The market will continue to be difficult for US and foreign firms to access because of the dominance of Chinese state-owned corporations, but these Chinese companies continue to need access to advanced technology.
- **Solar energy:** This is a relatively synergistic industry, which means that Chinese solar cell manufacturers buy their production lines internationally, and their output is subsequently used by US and other companies in fabrication and installation.
- **Nuclear energy:** Despite the rapid advances that China has made in nuclear power technology, there are still real opportunities for US-connected companies in the Chinese market. While Westinghouse is now foreign owned, it still has substantial assets in the United States, and further contracts with China would benefit the company and its US workforce. Whether new contracts will materialize depends both on whether Westinghouse is perceived as delivering cost-effective products on time and how rapidly Chinese competition for third-generation power plants actually develops. While the Chinese have expressed some frustration with delivery times for some elements of their current reactor projects, its own first third-generation

plant only began construction in May 2015. Consequently, it is still too early to tell if the Chinese nuclear industry will prove more effective at meeting deadlines and controlling costs.

If the nuclear market grows as large as some optimistic predictions (such as one from *Bloomberg Business* that suggested a $1 trillion market), there are rich opportunities for companies to compete.[970] If Chinese nuclear firms are able to sell their nuclear plants for two-thirds the price of a Westinghouse plant, this clearly will be an impediment, and thus the questions are both at what price can the Chinese deliver and whether it is possible for the competition to shave costs without impinging quality or safety. The fact that nuclear power plants are once again being built in the United States is a positive sign for the industry's ability to develop cost-effective and efficient deployment and to raise faith of potential customers in the product.[971]

Looking further into the future, the Chinese attraction to Westinghouse was the technology, and the question moving forward is whether any US-based companies will be offering next-generation technologies that Chinese buyers will find equally interesting.[972] General Electric and Hitachi, with US Department of Energy support, are developing a fourth-generation PRISM reactor that will be capable of recycling its own spent fuel.[973] DOE also awarded grants in January 2016 to two consortia, one led by X-Energy and MWX Technology for developing pebble bed technology, and another led by Southern Company and TerraPower to work on a molten chloride fast reactor.[974] These efforts are still in the R&D area. The Chinese already have a demonstration pebble bed reactor. The key question is whether there will be future US technologies that offer the kind of improved performance that attracted the Chinese to the AP1000.

International Engagement Opportunities

As China seeks energy abroad, there is an opportunity to engage with it on a broad range of international issues. China's own international interests are growing as its engagement expands and as more of its citizens and business interests are situated in foreign countries. The hoped-for result is an increasing awareness on the part of China's leadership of the effect poor governance has on its interests. Of course, Chinese government views of what makes good governance are not the same as those of the United States. However, the Chinese can still be good partners. They demonstrate a strong appreciation of the importance of well-trained bureaucrats, for example, but not in democracy promotion.

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[970] Stapczynski et al., "Westinghouse Races China for $1 Trillion Nuclear Power Prize."

[971] Umair Irfan, "Can the Next Generation of Reactors Spur a Nuclear Renaissance?" *ClimateWire*, July 1, 2015, http://www.eenews.net/stories/1060021132.

[972] Personal observation of the author from meetings prior to the Westinghouse deal with Chinese company officials and nuclear technology experts in academia. The consensus among nuclear experts at the time was that Westinghouse was the most modern, attractive technology.

[973] Maxx Chatsko, "General Electric Company's Advanced Nuclear Reactor Just Got a Boost from the DOE," *Motley Fool*, November 23, 2014, http://www.fool.com/investing/general/2014/11/23/general-electric-companys-advanced-nuclear-reactor.aspx.

[974] Eric Wesoff, "DOE Funds Advanced Pebble-bed and Molten-Salt Nuclear Reactor Development," Greentech Media, January 15, 2016, http://www.greentechmedia.com/articles/read/DOE-Funds-Advanced-Pebble-Bed-and-Molten-Salt-Nuclear-Reactor-Development.

Environmental Engagement Opportunities

The United States and China have reached successively more important understandings on climate change in recent years. What began with a joint announcement in November 2014 was followed by a US-China joint statement during President Xi Jinping's September 2015 visit to the United States. These statements reflect China's seriousness not just about domestic policies that have substantial economic or pollution abatement co-benefits, but also its genuine interest in developing sophisticated market-based mechanisms (specifically, a cap and trade system) and a desire to do so in a way that makes integration into a global system possible.

Chinese companies benefited enormously under the Kyoto Protocol's Clean Development Mechanism, and won the vast majority of projects under the plan between 2005 and 2012.[975] However, the Chinese are no longer eligible for new projects under this plan, which was designed to help developing countries develop their clean energy sectors. Consequently, the Chinese have been very interested in creating domestic carbon markets and integrating these with international markets. As the largest emissions trading market in the world, Chinese interest in integration has focused on Europe, but they clearly hope to see more global opportunities. The EU–China Joint Statement on Climate Change of June 2015 speaks specifically about developing EU–China emissions trading. The specific commitment to an emissions trading system in multiple sectors in the recent US–China joint statement indicates both China's commitment to developing these structures and an opportunity for the United States, were it to develop its own system, to trade with China.

There is considerable debate in China as to whether this national emissions trading system will be a success. It is important to differentiate this concern from whether China will deliver on its emissions reduction commitment. In author interviews with groups ranging from Chinese research institutes to international environmental organizations, there is a general consensus that China will be able to deliver on its commitments, and that the mechanisms for those commitments are already contained within Chinese economic, energy efficiency, and non-carbon fuel substitution policies. Emissions trading is seen as an important development for future carbon management and for integrating into a global system.

A number of experts, however, including Dr. Yang Fuqiang of the Natural Resources Defense Council, still believe that a carbon tax ultimately will prove easier to administer, and that it is quite possible that the Chinese government may choose to shift from a cap and trade to a carbon tax system in the future.[976] It is far too early to predict how the system will ultimately be organized. While there are indeed skeptics, it is also the case that some of the experimental plans, such as those in Guangdong Province, have been relatively successful and there are many in both business and policy circles who are enthusiastic about them.[977] What seems clear is that the Chinese government is interested in moving toward a system of market-based mechanisms, and the next few years will see policy innovation in this space.

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[975] UNEP DTU Project, Centre on Energy, Climate, and Sustainable Development, "CM Projects by Host Region," updated October 1, 2015, http://www.cdmpipeline.org/cdm-projects-region.htm#2.
[976] Author interviews.
[977] Author field interview.

China's willingness to commit to a more comprehensive plan in the joint statement than did the United States (whose commitment was focused on the power sector) and its promise of more than $3 billion in funds for South-South climate finance indicate the seriousness of the Chinese commitment to success in international climate negotiations. The statement was a key building block for the success of the December 2015 negotiations in Paris.[978]

Generally, China makes its commitments prior to major United Nations Framework Convention on Climate Change (UNFCCC) meetings and has little flexibility during the meetings themselves. This will be a continuing structural constraint that complicates such negotiations. However, it can be expected that China's potential to deliver on its climate change commitments, and even to exceed them, will grow in the coming years. In China's submission to the UNFCCC on June 30, 2015, it specifically committed to "achieve the peaking of carbon dioxide emissions around 2030 and making best efforts to peak early."[979] Experts differ on how early China can actually peak, but at least some within Chinese expert circles are pushing for a peak as early as 2022.[980] Thus, while China's public commitments are likely to leave it with more flexibility, it appears likely that China will be able to deliver more than what it promises.

China's more forward-leaning approach to international climate negotiations offers real opportunities for the United States, both to cooperate more with China and to have greater confidence that bolder US moves on climate change mitigation will be reciprocated by China. It also presents a risk. The Chinese appear to have calculated that it would be too costly for the next US president to renege on climate commitments made either bilaterally or in multilateral negotiations. It has taken seven years for the Obama administration to reassure the Chinese that the United States will not once again refuse to be a party to an agreement it helped negotiate, as was the case with the Kyoto Protocol. Currently envisioned agreements will not require ratification, as it is now understood by negotiation partners that the 67 US Senate votes needed are unlikely. However, the Chinese appear to believe that a global consensus on climate action is now strong enough that the United States will continue to abide by the commitments in the 2015 Joint Statement and the Paris Agreement. If this proves not to be the case, future cooperation could be severely damaged a substantially higher level of global warming gases could be produced.

The serious focus on air pollution also offers real opportunities for the United States. Most of the benefit of air pollution abatement clearly occurs in China and benefits the Chinese people. However, there is still a small but important amount of Chinese air pollution that enters the United States. It is not most of the air pollution in California, but it can be the threshold for cities that are otherwise having trouble keeping air quality within guidelines.[981] Current efforts in China should reduce this impact over the next decade. At the same time, the United States is actively promoting

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978 John D. Sutter and Joshua Berlinger, "Final Draft of Climate Deal Formally Accepted in Paris," CNN, December 14, 2015, http://www.cnn.com/2015/12/12/world/global-climate-change-conference-vote/.

979 "Enhanced Actions on Climate Change," Xinhua, June 30, 2015, http://news.xinhuanet.com/english/china/2015-06/30/c_134369837.htm.

980 Author interview with Jiang Kejun, Energy Research Institute, October 10, 2015.

981 Pollution from China can contribute as much as 20 percent of ozone-causing pollutants in California at certain seasons. Steve Scauzillo, "Air Pollution from China Undermining Gains in California, Western States," *San Gabriel Valley Tribune*, August 10, 2015, http://www.sgvtribune.com/environment-and-nature/20150810/air-pollution-from-china-undermining-gains-in-california-western-states.

air quality improvements around the world. The Chinese example will be key in further demonstrating that pollution abatement is not inconsistent with economic growth.

Moreover, China produces low-cost equipment that will make abatement much more affordable in other coal-reliant countries like India, Indonesia, Turkey, and South Africa. Currently, this is likely to be pollution abatement equipment, but the Chinese are also gearing up to be able to market CCS systems.

Risks for the United States

China's energy development also engenders risks for the United States. The most obvious is the indigenous innovation effort central to each of the energy-related plans. This could just drive healthy competition, but the emphasis on acquiring IP carries the risk of companies seeking to get IP in any way they can. Beyond this well-known risk, there is the reverse risk built into awards systems for Chinese researchers. There is an ongoing threat to academic paper and patent quality, as researchers work simply to fulfill targets. The risk at the very least is of incentivizing garbage patents and derivative papers. It can also lead to false findings.[982] These publications can be costly to others in the field since they may waste time and effort trying to confirm the results. If they occur often enough, they could also dampen cooperation, which would slow research progress.

China will also be a major international competitor. While China's international business activity may actually help its government be more aware of what is needed in terms of policy around the world, it is also the case that the Chinese will want their interests taken into account, such as ongoing business ties and investments. This greater interest by China in more countries may require more negotiation, especially in cases where the United States wishes to impose sanctions against other regimes. The Chinese will be working closely with Russia and Central Asia on energy development projects, and these countries may see China as a counterweight to the United States and Europe. China will also be increasingly interested in sea lanes. The energy plans specifically mention the concern that China does not control the vital sea lanes bringing its oil from the Middle East.

A final issue is safety. Energy systems of all kinds are dangerous. China has made substantial progress in reducing coal mine deaths, but as the August 2015 chemical fire and explosions in Tianjin demonstrates, (killing at least 179, injuring thousands, depositing cyanide in local waterways, and destroying considerable property) the risks around chemicals and fuels are varied and difficult to manage, especially in a rapidly growing economy.[983]

The FYPs address concerns about LNG terminals, but not about petrochemical plants and other potential hazards. Future safety concerns could challenge the regime to improve, as occurred with environmental regulations after the November 2005 chemical fire at a CNPC petrochemical facility in Jilin Province spilled 100 tons of toxic benzene and nitrobenzene into the Songhua River,

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[982] Felicia Sonmez, "Fake Peer Review Scandal Shines Spotlight on China," *Wall Street Journal*, August 25, 2015, http://blogs.wsj.com/chinarealtime/2015/08/25/fake-peer-review-scandal-shines-spotlight-on-china/.

[983] "China Explosions: What We Know About What Happened in Tianjin," BBC News, August 17, 2015, http://www.bbc.com/news/world-asia-china-33844084; "Tianjin Explosion: China Sets Final Death Toll at 173, Ending Search for Survivors," *Guardian*, September 12, 2015, http://www.theguardian.com/world/2015/sep/12/tianjin-explosion-china-sets-final-death-toll-at-173-ending-search-for-survivors.

threatening the water supply of downstream communities.[984] But they also carry with them the risk of creating public mistrust and political instability.

Safety is obviously vital for China's ambitious nuclear plan. Much more attention is paid to safety in the nuclear plan than elsewhere in the energy system, but there are structural problems that leave some risk. The first is the tendency in China—and elsewhere—of employees' reluctance to challenge bosses. The risk that issues do not rise up the chain of command is made greater by the weak position of the National Nuclear Safety Administration (NNSA, 国家核安全局) within MEP. MEP is stronger than it used to be, but its mission focuses on environmental pollutants. NNSA has no independent link to higher leadership, in contrast to the Nuclear Regulatory Commission in the United States. NNSA's budget is also constrained by the rate of growth of the overall MEP budget. MEP has been an advocate for NNSA, but this position within the government structure does keep safety somewhat hidden from higher leaders.

Expansion of Chinese nuclear plans brings with it an incredible demand for staffing. China is training new staff as fast as it can, but most of the staff in all parts of the nuclear industry—and its regulators—are quite young. This raises the question of whether safety institutions are capable of handling unexpected incidents and whether they would have the experience to identify them in time.

Both the Nuclear Regulatory Commission and the US Department of Energy already provide a great deal of nuclear safety and security advice and training to China.[985] The rate of expansion in China would challenge even a well-developed regulatory infrastructure, and many of China's nuclear regulatory staff are relatively new and inexperienced. While the Chinese government has attempted to be as careful and safety-conscious as possible—including the four-year pause after Fukushima—there is always a risk of a nuclear safety incident.

The demographic reality is that any nuclear accident in China would threaten tens of millions. All of China's nuclear facilities are along its populous east coast. Moreover, even people who are not actually at risk could perceive themselves to be in danger. There was considerable panic in China during the Fukushima accident.[986] The risk of public unrest in response to a genuine nuclear incident is an important concern. Thus, while a nuclear safety incident in China is unlikely to pose any type of direct contamination risk in the United States, it clearly is a political issue that the United States should be cognizant of. To this end, the best allies in preventing an incident are the Chinese nuclear safety officials themselves, who want more staffing and better training. The United States could provide such assistance through cooperative bilateral plans to support capacity-building.

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[984] United Nations Environment Programme, "The Songhua River Spill China, December 2005 Field Mission Report," http://www.unep.org/PDF/China_Songhua_River_Spill_draft_7_301205.pdf.
[985] Jane Nakano, "The United States and China: Making Nuclear Energy Safer," Center for Strategic and International Studies, July 2013, http://www.brookings.edu/~/media/events/2014/2/06-china-clean-energy/uschina-making-nuclear-energy-safer_jnakano.pdf; "US, China Sign Agreement to Establish Center of Excellence on Nuclear Security," NNSA, January 19, 2011, http://nnsa.energy.gov/mediaroom/pressreleases/chinacenterofexcellence01.19.11.
[986] "Chinese Panic-buy Salt Over Japan Nuclear Threat," Associated Press, March 17, 2011, http://www.theguardian.com/world/2011/mar/17/chinese-panic-buy-salt-japan.

CONCLUSIONS

China's state plans for military and civilian technology, energy, and industrial development have grown dramatically in size, importance, and impact over the past several decades, and especially in the twenty-first century. They have become a convenient policy tool for the pursuit of targeted strategies through top-down, state-directed mechanisms. Even as efforts are being taken to consolidate the runaway proliferation of these plans, new large-scale initiatives are being launched that are touted as crucial in China's transition to a new innovation-oriented development model.

In October 2015, the 5th Plenum of the 18th Central Committee, which deliberated on the 13th Five-Year Plan, highlighted the critical importance of state plans, stressing the need to "deeply implement innovation-driven development strategies, give play to the leading role of scientific and technology innovation in overall innovation, and enforce a number of national major science and technology projects."[987] One of the plans highlighted in the plenum communiqué was the Made in China 2025 plan, which has already become central in the dialogue surrounding China's long-term S&T development trajectory. The plan characterizes the Chinese government's efforts to improve the efficiency of its manufacturing sector, and, together with the One Belt, One Road strategy, forms a comprehensive blueprint to make China an advanced manufacturing nation.[988]

In examining the performance and impact of these state plans in the civilian, defense, and dual-use domains, a number of key findings emerge from this study.

Much promise, mixed results: Plans and projects individually and in aggregate have put forward lofty aspirations and goals in advancing China's development, but actual overall performance has been decidedly mixed. While there have been some noteworthy achievements, the large majority of plans have delivered far short of what they have promised. Many factors contribute to these shortcomings, from weak R&D capabilities to inadequate funding to structural flaws in the S&T management system.

Predominantly lower-end innovation with "Chinese characteristics": China's S&T development has been overwhelmingly at the lower end of the imitation-innovation spectrum, especially in:

1. **Advanced imitation**, or what the Chinese call 're-innovation,' which are technologies based upon foreign-derived technology and knowledge but localized and adapted to Chinese requirements. Key examples are high speed rail and the latest generation of Western-designed nuclear reactors.
2. **Crossover innovation**, which refers to products jointly developed by Chinese and foreign partners with significant technology and knowledge transfers to the local side that result in the creation of a R&D base. However, there is still considerable reliance on foreign countries for

[987] "Communiqué of the Fifth Plenary Session of the 18th CPC Central Committee," Xinhua, October 29, 2015.
[988] Interview with Scott Kennedy, deputy director and Freeman Chair in China Studies, Center for Strategic and International Studies, October 8, 2015, Washington, D.C.

technological and managerial input to ensure that projects come to fruition. The newly rolled-out C919 airliner is a prime example of crossover innovation.[989]

3. **Incremental innovation**, which is the limited updating and improvement of existing indigenously developed systems and processes.

Pivoting to higher innovation: The Chinese authorities have made the advancement to higher-end innovation a top priority in their latest development plans. At the 5th Plenum of the 18th Communist Party Congress in November 2015, Xi Jinping pointed out that a number of strategic technologies and research domains have been selected with the intention of pursuing major breakthroughs by 2030. They include aero-engines, quantum communications, intelligent manufacturing and robotics, deep space and deep sea probes, major new materials, and neurosciences.[990]

Innovation-driven development: The Xi Jinping administration is seeking to broaden China's long-standing model of top-down, state-led science, technology, and innovation development to embrace market-driven and bottom-up drivers under the slogan of "innovation-driven development." New policies and reforms are being drawn up, especially tied to the 13th FYP, incentivizing researchers, entrepreneurs, universities, and private companies to engage more intensively in research and development. Measures put forward include improving intellectual property protection, tackling industrial monopolies, supporting the development of the venture capital market, and implementing more supportive fiscal and taxation policies. If these initiatives are effectively implemented, this would allow innovation in China to become more balanced between state and market, sustainable, and internationally competitive.

The emergence of direct Sino-US defense technological competition: The United States has long enjoyed a huge defense technological pre-eminence over China, but this gap has narrowed over the last one to two decades, to the extent that the United States is now having to embark on a major new defense S&T offensive to preserve its dwindling superiority. The Third Offset Strategy and the Defense Innovation Initiative are the primary vehicles in the Pentagon's efforts at responding to the advances being made by China and other potential adversaries. Although these plans are modest when compared to the enormous and costly scale of the Cold War arms race between the United States and the Soviet Union, they nonetheless signal the first steps of direct Sino-US defense technological competition.

Innovation in China's defense S&T sector is more successful than in the civilian arena: China has invested heavily in its defense-related S&T plans and has enjoyed far more success than in the civilian sectors, as demonstrated in both the quality and quantity of output emerging from the research, development, and production pipeline over the past decade or more. This impressive progress is likely to continue and perhaps even accelerate in response to calls from top leaders, abundant funding, and assessments of an intensifying global revolution in military affairs.

[989] "China's First Big Passenger Plane Rolls Off Production Line," Xinhua, November 2, 2015, http://news.xinhuanet.com/english/2015-11/02/c_134775856.htm.

[990] "Xi Jinping Explains the 'Recommendations of the Party Center on the 13th Five-Year National Economic and Social Development Plan'" (习近平 关于"中共中央关于制定国民经济和社会发展第十三个五年规划的建议"的说明), Xinhua, November 3, 2015, http://news.xinhuanet.com/politics/2015-11/03/c_1117029621.htm.

The Chinese defense S&T apparatus is moving to higher-end innovation: The Chinese defense S&T system appears to be making an important shift from focusing on absorption to the development of more innovative capabilities, especially in meeting the PLA's more demanding requirements. With considerable attention paid to the United States as China's primary military technological competitor, much of the R&D is directed to asymmetric and deterrence capabilities. Despite the progress being made, deep-seated structural problems in the defense S&T and armaments system represent serious barriers to continuing improvement. These obstacles include compartmentalization, weak institutionalization, and an underdeveloped governance regime.

China's technological development has so far been a benefit to the United States, but the longer-term horizon is more uncertain: The detailed review of eleven industries conducted in this report indicates that at present, most of these industries have a positive impact for the United States. This is because of China's large market demand for the technologies and the lack of current Chinese indigenous expertise or technology know-how. Over the next several years, US firms will face intensifying competition as China's domestic industries make technological advances with support from state plans. This is likely to be the case for the 5G technology, addictive manufacturing, cloud computing, global navigation satellite systems, and integrated circuits sectors. Over the longer-term, ten-year horizon, the Chinese industries that will provide the toughest competition for the United States will be ICT, 5G, cloud computing, global navigation satellite systems, and integrated circuits. In other sectors, including additive manufacturing, advanced robotics, biopharmaceuticals, medical devices, electric vehicles, and nanomaterials, the impact on US firms from China's technology advances will be more mixed. (see Table 16, page 253.)

Domestic demand drives innovation in the energy sector: S&T efforts in the Chinese energy sector are framed in the context of the pursuit of indigenous innovation, which is the desire to localize production and intellectual property. The Chinese energy industry has been successful in areas such as coal-fired power plants where domestic demand is high. They have been less successful and have devoted fewer resources in areas where they have traditionally been relatively modest consumers, such as gas turbines. However, as energy demands shift, the Chinese energy sector is likely to seek greater IP in the areas in which they lag.

Techno-national opportunism and indigenous innovation are powerful strategic principles in the nature and approach of Chinese state plans: Techno-nationalism advocates that a state-controlled and closed-door approach to technological and industrial development is the best way to safeguard national security, economic competiveness, and international status. Emphasis is placed on nurturing indigenous capabilities through the adoption of highly regulated protectionist regimes that sharply restrict foreign direct investment but encourage the one-way importation of advanced technology and knowledge. The MLP is a leading example of a plan that is avowedly techno-nationalistic in nature.

Hand in glove with techno-nationalism is indigenous innovation, which is widely referred to in Chinese state plans. What indigenous innovation actually means, however, is far from clear. When the term first appeared in the MLP, it was defined as a way to promote original innovation, re-assembling existing technologies in different ways to produce new breakthroughs, and the absorption and upgrading of imported technologies, of which the latter is the most important way to advance innovation. This continues to be the standard definition of indigenous innovation to the present day.

The Chinese authorities have devised at least half a dozen policy instruments to advance their science, technology, energy, and industrial development guided by the techno-nationalist and indigenous innovation principles: 1) sectoral protectionism; 2) the cultivation of local and national champions; 3) pushing hard for technology transfers; 4) the use of state catalogues to regulate investment and technology imports; 5) the promotion of Chinese technology standards domestically and internationally; and 6) an increasingly vigorous “going out” strategy to open up foreign markets for Chinese products as well as to secure energy and other critical supplies for the country.

Estimating the future impact of Chinese high-tech imports on US jobs: A sensitivity analysis was conducted to calculate the range of outcomes that can be reasonably anticipated as to the possible magnitude of impacts to the US labor market from Chinese manufactured imports out to 2020. To begin with, a range of estimates were developed based on trading scenarios associated with eight high-tech sectors: telecommunications equipment; electric vehicles; pharmaceuticals; medical instruments; additive manufacturing, advanced robotics, biopharmaceuticals, and integrated circuits. The worst-case outcome is that the United States would face a $55 billion increase in net imports from China by 2020. The best-case scenario is that US net imports from China will decline by almost $35 billion by 2020. Using the worst-case $55 billion figure, our estimate is that the United States would lose 431,600 manufacturing jobs by 2020. For the best-case scenario of a net $35 billion gain in US exports, US manufacturing employment would increase by 273,100 jobs. It is highly unlikely that either of these extreme values will be realized, and a more likely outcome is a mixed one in which the overall impact on US net imports from China is likely to be close to zero.

In conclusion, state plans have become a convenient, almost indispensable, policy tool for the Chinese authorities, even if their overall effectiveness is questionable. While there have been some noteworthy achievements, the large majority of plans have delivered far short of what they have promised. Many factors contribute to these shortcomings, from weak R&D capabilities to inadequate funding to structural flaws in the S&T management system. All the indicators suggest, however, that the Chinese authorities will most likely channel even more resources to these plans, while at the same time carrying out reforms to address these weaknesses.

How Should the United States Respond?

The report has identified a number of ways in which the United States can respond to China’s state-directed science, technology, energy, and industrial development. First is the importance of identifying core areas for priority investment and support. It encountered a similar challenge in the 1980s and 1990s as Japan grew and advanced in technological competitiveness. During that period, the United States identified core areas where it wanted to maintain competency and technological advantage. US government outlays on these projects were modest, but helped galvanize an effective private sector response.[991]

[991] Interview with Peter Cowhey, dean of the School of Global Policy and Strategy, UC San Diego, October 12, 2015.

Current US strategy lacks a similar approach. The BRAIN initiative represents one example where the United States has provided significant funding to advance an area where it already possesses much academic and industry expertise, and which will have large technological benefits and positive spillovers to society. However, this plan is the exception rather than the rule. Other plans, such as the National Manufacturing Initiative, may be headed in the right direction, but their impact remains small compared to what is needed to keep the United States at the forefront. Part of the need is for adequate funding to these core industries, but an additional need is to adequately analyze and map the sectors in which the United States should maintain its competence. Two areas that might be particularly important going forward are advanced materials and sensors.

Second, the US defense S&T and industrial sectors are beginning to respond to China's rising technological challenge, but much more needs to be done over the long term. The Third Offset Strategy and the Defense Innovation Initiative represent a belated recognition of the need to counter Chinese efforts to blunt US power projection capability. These efforts deserve to be supported throughout the remainder of the Obama administration. Moreover, if they are to have a long-term impact on the US strategic position, they will need to continue after President Obama leaves office.

Such an offset strategy, if implemented consistently over time, holds the promise of eroding the effectiveness of Chinese counter-intervention systems. It would also deny the PLA leadership the type of war it has been planning for decades, forcing it to either double-down on its investment in anti-access capabilities or seek a new approach. It also holds the potential to alter the decision-making calculus of the Chinese leadership, markedly increasing the cost of pursuing a strategy of maritime expansion and potentially rechanneling Chinese attention toward the Asian continent.

Third, the report has addressed how the United States can do a better job of protecting against unauthorized Chinese technology acquisitions. These efforts should include both improved information security and updated technology transfer restrictions. Information security forms the first line of defense for US technology, and China has been able to steal critical information because of poor information security practices. Information security measures in both government and private industry should be strengthened. Industrial espionage on the scale that China has been conducting cannot and should not be isolated from the overall Sino-American relationship. US leaders must make it clear that the continuation of such activities, whether actively abetted or passively tolerated by the Chinese government, will have a tangible negative impact on the US–China relationship. The United States may have to take measures that will trigger Chinese retaliation. Absent such action, however, it is doubtful that the Chinese defense S&T sector will forgo the considerable benefits that accrue to it from stealing US technology.

Given the vital importance of information security and cybersecurity for the United States and China, the issue requires the attention and engagement of the highest levels of the two countries' leadership. One recommendation is that the US and Chinese presidents should be actively and personally engaged in meeting with each other to address concerns and find ways to forge robust and enforceable bilateral agreements to curb the most dangerous and egregious practices, in a similar approach to the US–Soviet nuclear arms control treaties during the Cold War.

Technology transfer restrictions also need to be updated, both to reflect the current international technology market and to maximize their effectiveness. Moreover, it is in the national interest of the United States for the government and private industry to work cooperatively to develop best practices and share threat information. To be effective, however, such measures should prioritize those technologies that are likely to provide the greatest battlefield edge in the future. In the defense and national security realm, this would include space and cyber capabilities, unmanned systems, high-speed propulsion, advanced aeronautics, autonomous systems, electromagnetic rail guns, and directed-energy systems.

Appendix A: Chinese State Strategies, Plans, and Guidance on Civilian, Defense, and Dual-Use Science, Technology, Industrial, and Energy Development

National level plans	Sub-sectoral level: Short-, medium-, and long-term plans
Sectoral development strategies	Policies and guidance
Sectoral level: Short-, medium-, and long-term plans	Accompanying guidance and official opinions

National plans and strategies					
Name (English)	**Name (Chinese)**	**Issue date**	**Sector/area**	**Time span**	**Responsible agencies**
13th Five-Year National Economic and Social Development Plan (2016–2020)	国民经济和社会发展第十三个五年规划纲要	2016	Comprehensive	2016–2020	State Council
Science and technology plans and strategies					
863 High-Technology Research and Development Plan (863 Plan) Civilian Component	国家高技术研究发展计划(863 计划)-民口	March 1986	Strategic technologies	1986–present	MOST, COSTIND/ SASTIND, PLA GAD
National Basic Research Plan (973 Plan)	国家重点基础研究发展计划(973 计划)	1997	Comprehensive	1997–present	State Science, Technology, Education Leading Small Group, and MOST
Medium- and Long-Term Science and Technology Development Plan (2006–2020)	国家中长期科学和技术发展规划纲要 (2006–2020)	February 2006	Comprehensive	2006–2020	State Council
Notice to Implement Complementary Policies for National Medium- and Long-term Science and Technology Development Plan (2006–2020)	实施《国家中长期科学和技术发展规划纲要(2006–2020 年)》若干配套政策的通知	March 2008	Comprehensive	2006–2020	State Council
National Intellectual Property Strategy	国家知识产权战略	June 2008	IPR	2008–2020	State Council
12th Five-Year Science and Technology Development Plan	国家"十二五"科学和技术发展规划	July 2011	Comprehensive	2011–2015	MOST
National Medium- and Long-Term Major Scientific and Technological Infrastructure Construction Plan (2012–2030)	国家重大科技基础设施建设中长期规划（2012–2030 年）	March 2013	Infrastructure construction	2012–2030	State Council
12th Five-Year Plan for National Indigenous Innovation Capacity Building	"十二五"国家自主创新能力建设规划	May 2013	Innovation	2013–2015	State Council

Science and technology plans and strategies (continued)					
Name (English)	**Name (Chinese)**	**Issue date**	**Sector/area**	**Time span**	**Responsible agencies**
Plan on Deepening Reform of the Central Government S&T Plan (Projects, Funds, etc.) Management	关于深化中央财政科技计划（专项、基金等）管理改革的方案	January 2015	S&T Funding	2014–2017	State Council
Action Plan to Implement the National Intellectual Property Strategy (2014–2020)	深入实施国家知识产权战略行动计划（2014–2020 年）	January 2015	IPR	2014–2020	State Council
2015 Key Work Points on Combating IPR Infringement and Sale of Counterfeit and Shoddy Goods	关于印发 2015 年全国打击侵犯知识产权和制售假冒伪劣商品工作要点的通知	March 2015	IPR	2015	State Council
State Council Opinions on Deepening System and Organizational Reform and Accelerating the Implementation of an Innovation-Driven Development Strategy	中共中央国务院关于深化体制机制改革加快创新驱动发展战略的若干意见	March 2015	Comprehensive	2015–2020	State Council
State Council Opinions on Policies to Promote Mass Innovation and Entrepreneurship	国务院关于大力推进大众创业万众创新若干政策措施的意见	June 2015	Innovation and entrepreneurship	2015	State Council
13th Five-Year Science and Technology Development Plan	国家”十三五”科学和技术发展规划	2016	Comprehensive	2016–2020	MOST
13th Five-Year Scientific and Technological Innovation Plan	“十三五”科技创新规划	2016	Innovation	2016–2020	MOST
13th Five-Year Technical Standards Special Plan	“十三五”技术标准专项规划	2016	Standards	2016–2020	MOST, General Administration of Quality Supervision, Inspection, and Quarantine
13th Five-Year National Science and Technology Major Project Development Plan	国家科技重大专项”十三五”发展规划	2016	Comprehensive	2016–2020	MOST
Defense and dual use plans and strategies					
863 High-Technology Research and Development Plan (863 Plan) Military Component	国家高技术研究发展计划(863 计划)-军口	March 1986	Strategic technologies	1986–present	MOST, COSTIND/ SASTIND, PLA GAD
New High-Technology Weapons Plan (995 Plan)	新型高科技武器计划(995 计划)	1999	Defense technology	1999–present	CMC, PLA GAD
2006–2020 Medium- and Long-Term Defense Science and Technology Development Plan (MLDP)	国防科技工业中长期科学和技术发展规划纲要 (2006–2020)	May 2006	Defense R&D	2006–2020	COSTIND/ SASTIND

Defense and dual use plans and strategies (continued)					
12th Five-Year Defense Science and Technology Industry Plan	国防科技工业十二五规划	2011	Comprehensive	2011–2015	SASTIND
12th Five-Year Plan for Weapons and Equipment Construction	“十二五”武器装备建设规划	2011	Weapons and equipment RDA	2011–2015	CMC, PLA GAD
13th Five-Year Defense Science and Technology Industry Plan	国防科技工业十三五规划	2016	Comprehensive	2016–2020	SASTIND
13th Five-Year Civil-Military Integration Plan	军民融合十三五规划	2016	Comprehensive	2016–2020	MIIT
13th Five-Year Plan for Weapons and Equipment Construction	“十三五”武器装备建设规划	2016	Weapons and equipment RDA	2016–2020	CMC Armament Development Department
Energy sector plans and strategies					
Comprehensive					
National Energy Technology 12th Five-Year Plan	国家能源科技”十二五”规划(2011–2015)	December 2011	Energy	2011–2015	NEA
12th Energy Development Five-Year Plan	能源发展”十二五”规划	January 2013	Energy	2013–2015	State Council
Energy Development Strategy Action Plan (2014–2020)	能源发展战略行动计划(2014–2020 年)	November 2014	Energy	2014–2020	State Council
13th Energy Development Five-Year Plan	能源发展”十三五”规划	2016	Energy	2016–2020	NEA
Fossil fuels					
Petrochemical and Chemical Industry 12th Five-Year Plan	石化和化学工业”十二五”发展规划	December 2011	Petroleum	2011–2015	MIIT
12th Five-Year Plan for Coal Industry Development	煤炭工业发展”十二五”规划	March 2012	Coal	2012–2015	NDRC
12th Five-Year Special Plan for Purified Coal Technology Development	洁净煤技术科技发展”十二五”专项规划	March 2012	Coal	2012–2015	MOST
12th Five-Year Plan for Natural Gas Development	天然气发展”十二五”规划	October 2012	Gas	2012–2015	NDRC
13th Five-Year Plan for Coal Industry Development	煤炭工业发展”十三五”规划	2016	Coal	2016–2020	NDRC, NEA
New and renewable energy					
Medium- and Long-Term Development Plan for Renewable Energy in China (2007–2020)	可再生能源中长期发展规划(2007–2020)	August 2007	Renewable energy	2007–2020	NDRC
Shale Gas Development Plan (2011–2015)	页岩气发展规划(2011–2015 年)	March 2012	Shale gas	2011–2015	NDRC, MOF, Ministry of Land and Resources, NEA

New and renewable energy (continued)					
12th Five-Year Special Plan for Wind Power Technology Development	风力发电科技发展"十二五"专项规划	March 2012	Wind	2012–2015	
12th Five-Year Special Plan for Solar Energy Technology Development	太阳能发电科技发展"十二五"专项规划	March 2012	Solar	2012–2015	MOST
Electric Vehicle Technology 12th Five-Year Special Plan	电动汽车科技发展"十二五"专项规划	March 2012	Electric vehicle	2012–2015	MOST
12th Five-Year Plan for Bioenergy Technology Development	生物质能源科技发展"十二五"重点专项规划	May 2012	Bioenergy	2012–2015	MOST
Renewable Energy 12th Five-Year Plan	可再生能源发展十二五规划	August 2012	Renewable energy	2012–2015	NEA
12th Five-Year Plan for Wind Power Development	风电发展"十二五"规划	September 2012	Wind	2012–2015	MOST
12th Five-Year Plan for Solar Energy Development	太阳能发电发展"十二五"规划	September 2012	Solar	2012–2015	NEA
Nuclear Safety and Radioactive Pollution Prevention 12th Five-Year Plan and Vision of 2020	核安全与放射性污染防治"十二五"规划及 2020 年远景目标	October 2012	Nuclear	2012–2020	MEP, NDRC, MOF, NEA, SASTIND
12th Five-Year Plan for Hydropower Development	水电发展"十二五"规划	November 2012	Hydro	2012–2015	NEA
Renewable Energy 13th Five-Year Plan	可再生能源发展十三五规划	2016	Renewable energy	2016–2020	NEA
13th Five-Year Plan for Solar Energy Development	太阳能利用"十三五"规划	2016	Solar	2016–2020	NEA
13th Five-Year Plan for Nuclear Power Development	核电"十三五"规划	2016	Nuclear	2016–2020	NEA
Energy efficiency					
12th Five-Year Plan for Industrial Energy Conservation	工业节能"十二五"规划	February 2012	Energy saving	2012–2015	MIIT
Smart Grid Major Science and Technology Industrialization Project 12th Five-Year Plan	智能电网重大科技产业化工程"十二五"专项规划	March 2012	Energy efficiency	2012–2015	MOST
12th Five-Year Plan for Industrial Energy Conservation	"十二五"建筑节能专项规划	May 2012	Energy saving	2012–2015	Ministry of Housing and Urban-Rural Development
12th Five-Year Plan for Green Energy Industry Development	"十二五"节能环保产业发展规划	June 2012	Energy saving	2012–2015	State Council
Energy Saving 12th Five-Year Plan	节能减排"十二五"规划	August 2012	Energy saving	2012–2015	State Council

Environment and climate change					
12th Five-Year Plan for the Environmental Health Work of National Environmental Protection	国家环境保护"十二五"规划	December 2011	Environmental protection	2011–2015	State Council
12th Five-Year Greenhouse Gas Emission Control Plan	"十二五"控制温室气体排放工作方案	January 2012	Climate change	2011–2015	State Council
Climate Change Action Plan for Industries (2012–2020)	工业领域应对气候变化行动方案(2012-2020)	January 2013	Climate change	2012–2020	MIIT, NDRC, MOF
The Action Plan for Air Pollution and Control	大气污染防治行动计划	September 2013	Environmental protection	2013–2017	State Council
National Climate Change Plan (2014–2020)	国家应对气候变化规划(2014-2020 年)	September 2014	Climate change	2014–2020	NDRC
Industrial economy plans and strategies					
Industry Transformation and Upgrading Plan (2011–2015)	工业转型升级规划(2011–2015 年)	December 2011	Comprehensive	2011–2015	MIIT
Decision of the State Council on Accelerating the Development of Strategic Emerging Industries	国务院关于加快培育和发展战略性新兴产业的决定	October 2010	Comprehensive	2010–2020	State Council
Notice to Strengthen Strategic Emerging Industry Intellectual Property Rights	关于加强战略性新兴产业知识产权工作若干意见的通知	April 2012	IPR	2012–2020	State Council
12th Five-Year Plan on Development of Strategic Emerging Industries	"十二五"国家战略性新兴产业发展规划	July 2012	Comprehensive	2012–2020	State Council
Old Industrial Bases Adjustment and Reform Plan (2013–2022)	全国老工业基地调整改造规划(2013–2022 年)	March 2013	Comprehensive	2013–2022	NDRC
National Informatization Development Strategy (2006–2020)	2006–2020 年国家信息化发展战略	May 2006	ICT	2006–2020	State Council
Opinions on Promoting the Development of Information Technology and Ensuring Information Security	大力推进信息化发展和切实保障信息安全的若干意见	June 2012	ICT	2012–2015	State Council
"Broadband China" Strategy and Implementation Plan	"宽带中国"战略及实施方案	August 2013	ICT	2013–2020	State Council
State Council Opinions on Promoting Information Consumption and Expanding Domestic Demand	国务院关于促进信息消费扩大内需的若干意见	August 2013	ICT	2013–2015	State Council
Software and Information Technology Service Industry 12th Five-Year Plan	软件和信息技术服务业"十二五"发展规划	April 2012	ICT	2012–2015	MIIT
Internet Industry 12th Five-Year Plan	互联网行业"十二五"发展规划	May 2012	ICT	2012–2015	MIIT

Industrial economy plans and strategies (continued)					
Name (English)	**Name (Chinese)**	**Issue date**	**Sector/area**	**Time span**	**Responsible agencies**
12th Five-Year Special Plan for Cloud Computing Technology Development	中国云科技发展"十二五"专项规划	September 2012	ICT	2012–2015	MOST
State Council Opinions on Promoting Innovative Development of Cloud Computing and Fostering the New Form of Information Industry	国务院关于促进云计算创新发展培育信息产业新业态的意见	January 2015	ICT	2015–2020	State Council
Opinions on Promoting the Development of the Satellite Application Industry	关于促进卫星应用产业发展若干意见	November 2007	ICT	2007–2020	NDRC, COSTIND/ SASTIND
Notice on Organizing Applications for Satellite High-Technology Industrialization Projects	关于请组织申报卫星应用高技术产业化专项的通知	January 2008	ICT	2008–2009	NDRC
12th Five-Year Plan for Informatization of Highway and Waterway Transportation	公路水路交通运输信息化"十二五"发展规划	April 2011	ICT	2010–2015	Ministry of Transport
National Medium- and Long-term Development Plan for Navigation Satellites	国家卫星导航产业中长期发展规划	October 2013	ICT	2013–2020	State Council
National Geographic Information Industry Development Plan (2014–2020)	国家地理信息产业发展规划(2014–2020)	August 2014	ICT	2014–2020	NDRC, National Administration of Surveying, Mapping, and Geoinformation
National Integrated Circuit Industry Development Outline	国家集成电路产业发展推进纲要	June 2014	ICT	2014–2030	MIIT
"Internet Plus" Plan Action Guidelines	"互联网+"行动指导意见	July 2015	ICT	2015–2025	State Council
Integrated Circuit Industry 13th Five-Year Plan	集成电路产业"十三五"规划	2016	ICT	2016-2020	MIIT
Internet Industry 13th Five-Year Plan	互联网行业"十三五"发展规划	2016	ICT	2016-2020	MIIT
Big Data 13th Five-Year Plan	大数据产业"十三五"发展规划	2016	ICT	2016-2020	MIIT
12th Five-Year Special Plan for Major National Scientific Research Plan on Nano Research	纳米研究国家重大科学研究计划"十二五"专项规划	May 2012	Manufacturing	2012–2015	MOST
12th Five-Year Plan for Service Robot Technology Development	服务机器人科技发展"十二五"专项规划	April 2012	Manufacturing	2012–2015	MOST
Guidelines on Promoting the Development of Industrial Robots	关于推进工业机器人产业发展的指导意见	December 2013	Manufacturing	2013–2020	MIIT

Industrial economy plans and strategies (continued)					
Name (English)	**Name (Chinese)**	**Issue date**	**Sector/area**	**Time span**	**Responsible agencies**
National Additive Manufacturing Industry Promotion Plan (2015–2016)	国家增材制造产业发展推进计划(2015–2016 年)	February 2015	Manufacturing	2015–2016	MIIT, NDRC, MOF
Made in China 2025	中国制造 2025	May 2015	Manufacturing	2015–2025	MIIT, CAE
13th Five-Year Plan on Development of Strategic Emerging Industries	“十三五”国家战略性新兴产业发展规划	2016	Comprehensive	2016–2020	State Council
13th Five-Year Plan for Advanced Manufacturing Technology	先进制造技术领域”十三五”规划	2016	Manufacturing	2016–2020	MIIT
Intelligent Manufacturing 13th Five-Year Plan	智能制造”十三五”发展规划	2016	Manufacturing	2016–2020	MIIT
Robotics Industry 13th Five-Year Plan	机器人产业”十三五”发展规划	2016	Manufacturing	2016–2020	MIIT
13th Five-Year New Materials Plan	新材料产业发展”十三五”规划	2016	Manufacturing	2016–2020	MIIT
Joint Action Plan for Indigenous Innovation of China’s High Speed Rail	中国高速列车自主创新联合行动计划	February 2008	Transportation	2008–2020	MOST, Ministry of Railways
New Energy Vehicles Industry Development Plan (2012–2020)	节能与新能源汽车产业发展规划(2012–2020 年)	July 2012	Transportation	2012–2020	State Council
General Office of the State Council Opinions on Accelerating the Promotion of New Energy Vehicles	国务院办公厅关于加快新能源汽车推广应用的指导意见	July 2014	Transportation	2014–2020	State Council
13th Five-Year Electric Vehicles Development Plan	十三五电动汽车产业发展规划	2016	Transportation	2016–2020	MOST
12th Five-Year Plan for Biotechnology Development	十二五生物技术发展规划	November 2011	Medical and healthcare	2011–2015	MOST
12th Five-Year Plan for Medical Devices Industry Development	医疗器械科技产业十二五专项规划	December 2011	Medical and healthcare	2011–2015	MOST
Biotechnology Industry Development Plan	生物产业发展规划	December 2012	Medical and healthcare	2013–2015	State Council
13th Five-Year Pharmaceutical Industry Development Plan	医药工业十三五发展规划	2016	Medical and Healthcare	2016–2020	MIIT

Appendix B: 2015 Catalogue of Encouraged Technologies and Products for Imports

Advanced Technology Encouraged Imports 鼓励引进的先进技术

No.	Technology (Chinese)	Technology (English)
A1	页岩气开发利用技术（水力压裂技术和水平井钻井技术）	Exploitation and utilization technology of shale gas (hydraulic fracturing and horizontal hole drilling techniques)
A2	煤层气（瓦斯）地面抽采及综合利用技术	Ground drainage and comprehensive utilization technique for coal bed methane (gas)
A3	采掘装备自动化与工况检测系统技术	Mining equipment, automation technology, and working condition detection system technology
A4	其他高效综采成套装备和煤矿快速掘进与支护设备制造技术	Other manufacturing technology of efficient mechanized mining equipment and coal rapid excavation and shoring equipment
A5	地下矿山无轨采矿设备自动化技术	Trackless equipment and automation technology for underground mining
A6	煤层气（瓦斯）勘探及开发利用关键设备的设计制造技术	Design and manufacturing technologies of key equipment of coal-bed methane (gas) exploration and development and utilization
A7	煤炭液化、地下气化关键设备的设计制造技术	Coal liquefaction and underground gasification key equipment design and manufacturing technology
A8	煤矿地质、石油及地球物理勘探关键设备的设计制造技术	Design and manufacturing technologies of key equipment of coal geology, petroleum, and geophysical exploration
A9	核材料及装置的设计制造技术	Nuclear materials and device design and manufacturing technology
A10	可再生能源、氢能等新能源领域关键设备的设计制造技术	Design and manufacturing technologies of key equipment in the fields of renewable energy, hydrogen, and other new energy technologies
A11	烟道二氧化碳捕集、驱油、埋存一体化技术及二氧化碳开采天然气和回注技术	Integrated technology of capturing, displacement, and storage for flue carbon dioxide and natural gas exploitation technology using carbon dioxide sequestration and reinjection technology
A12	大功率天然气输送装置先进设计技术	Advanced design technology of high-power natural gas delivery devices
A13	天然气输送管线增压站用燃气轮机技术	Gas turbine technology for natural gas transmission pipeline booster stations
A14	天然气液化混合冷剂循环压缩机技术	Circular compressor technology for mixed refrigerant liquefied natural gas
A15	分布式光伏发电技术（技术标准：光伏发电系统效率 > 80%；总电流谐波畸变率 < 3%；储能效率> 90%）	Distributed photovoltaic power generation technology (technical standard: photovoltaic system efficiency > 80%; total harmonic distortion rate < 3%; storage efficiency > 90%)
A16	闪速熔炼、闪速吹炼铜冶炼技术	Flash smelting and copper smelting processing technology
A17	烧结制品窑炉工艺参数控制关键技术	Key technologies for sintered product kiln process parameter control
A18	大规格高强度圆环链制造技术	Large-sized, high-strength ring chain manufacturing technology
A19	万万亿次高性能计算机的设计制造技术	Design and manufacturing technology of 10 petaflop computer
A20	航空发动机、燃气轮机涡轮叶片及高温热部件精密铸造技术	Aeroengine, gas turbine blade, and high-temperature component casting technology

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A21	65 nm 及以下大规模数字集成电路设计、工艺制造技术，0.18 μm 及以下模拟、数模集成电路设计、工艺制造技术，SoC 芯片和关键 IP 核、新型高密度集成电路封装与测试技术，上述技术产品专用设备的设计制造技术和专用材料的生产技术	65 nm and below, large-scale digital integrated circuit design, process manufacturing technology, 0.18 μm and below analog, digital-analog integrated circuit design, process manufacturing technology, SoC chips and key IP core, new-style high-density integrated circuit packaging and testing technology, design and manufacturing technology of special equipment and materials for these technology products
A22	TFT-LCD、OLED 面板、配套材料制造技术和专用设备的设计制造技术，显示-触控一体化、柔性显示制造技术和专用设备的设计制造技术，3D 显示、激光显示制造技术和专用设备的设计制造技术	Manufacturing technology of TFT-LCD, PDP, OLED panels, display-touch integration, flexible display, 3D display and laser display, and supporting materials and dedicated equipment design and manufacturing technology
A23	3D 打印（增材制造）及其专用设备制造和专用材料制造技术	Manufacturing technology of 3D printing (additive manufacturing), special equipment and material for these technology products
A24	便携式计算机设计制造技术	Portable computer design and manufacturing technology
A25	高性能、大容量存储系统设计制造技术	High-performance, high-capacity storage system design and manufacturing technology
A26	高速移动数据通信技术	High-speed mobile data communication technology
A27	基于开放源码（OPEN SOURCE）的软件技术	Open-source-based software technology
A28	精密高效立、卧式加工中心设计制造技术	Precise and high-speed vertical, horizontal machining center design and manufacturing technology
A29	立式铣车复合加工中心设计制造技术	Vertical milling and turning composite machining center design and manufacturing technology
A30	五轴联动加工中心设计制造技术	Five-axis linkage machining center design and manufacturing technology
A31	精密数控车床及车削中心设计制造技术	Precision CNC lathes and turning centers design and manufacturing technology
A32	高速数控车床及车削中心卧式铣车复合加工中心设计制造技术	High-speed CNC lathes and turning centers horizontal milling and turning composite machining center design and manufacturing technology
A33	高速、精密大型数控滚齿机设计制造技术	High-speed, large-sized precision CNC hobbing machine design and manufacturing technology
A34	高速、精密大型数控磨齿机设计制造技术	High-speed, large-sized precision CNC gear teeth grinding machine design and manufacturing technology
A35	难加工材料轴类零件超高速精密外圆磨床设计制造技术	Difficult-to-process material shaft parts ultra-high-speed precision cylindrical grinding machine design and manufacturing technology
A36	数控切点跟踪曲轴磨床设计制造技术	CNC cut point tracking crankshaft grinding machine design and manufacturing technology
A37	精密、复合、数控磨床设计制造技术	Precision, composite, CNC grinding machine design and manufacturing technology
A38	精密曲面成形数控磨床设计制造技术	Precision cambered surface modeling CNC grinding machine design and manufacturing technology
A39	五轴联动叶片数控磨床设计制造技术	Five-axis linkage blade CNC grinding machine design and manufacturing technology
A40	纳米级精度微型数控磨床设计制造技术	Nano-grade precision micro CNC grinding machine design and manufacturing technology

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A41	五轴联动高速、精密、数控工具磨床设计制造技术	Five-axis linkage high-speed, precision CNC tool grinding machine design and manufacturing technology
A42	大型、精密、高效、数控螺纹加工设备设计制造技术	Large-scale, precision, efficient CNC thread processing equipment design and manufacturing technology
A43	高档数控珩磨机设计制造技术	High-end CNC honing machine design and manufacturing technology
A44	高速龙门五轴加工中心设计制造技术	High-speed five-axis gantry machining center design and manufacturing technology
A45	龙门铣车复合加工中心设计制造技术	Gantry milling and turning composite machining centers design and manufacturing technology
A46	重型五轴龙门加工中心设计制造技术	Heavy-duty five-axis gantry machining center design and manufacturing technology
A47	五轴联动数控落地铣镗床设计制造技术	Five-axis CNC floor milling and boring machine design and manufacturing technology
A48	重型曲轴铣车复合加工中心设计制造技术	Heavy-duty crankshaft milling and turning composite machining centers design and manufacturing technology
A49	超重型数控落地镗铣床设计制造技术	Super-heavy-duty CNC floor milling and boring machine design and manufacturing technology
A50	大直径、超长、深孔加工的车、珩磨复合加工中心设计制造技术	Large-diameter, ultra-long, deep hole-machining turning and honing composite machining center design and manufacturing technology
A51	高速、精密主轴设计制造技术	High-speed, precision principal axis design and manufacturing technology
A52	大功率、大扭矩双摆铣头设计制造技术	High-power, large-torque double pendulum milling head design and manufacturing technology
A53	高速、重载精密滚珠丝杠及直线导轨设计制造技术	High-speed, heavy-load precision ball screws and linear guide design and manufacturing technology
A54	高精、高速数控转台设计制造技术	High-precision, high-speed CNC turret design and manufacturing technology
A55	大型刀库及自动换刀装置设计制造技术	Large tool storage and automatic tool change device design and manufacturing technology
A56	全功能数控动力刀架设计制造技术	Full-featured CNC dynamic turret design and manufacturing technology
A57	高速防护装置设计制造技术	High-speed protective device design and manufacturing technology
A58	高速数控机床用新型数控刀具、刀柄系统、高效可转位刀具、超硬刀设计制造技术	New-style CNC cutting tools, tool holder system, high-performance indexable cutting tools, super-hard tool design and manufacturing technology for high-speed CNC machines
A59	全数字高档数控装置、全数字交流伺服电机、主轴电机及驱动装置设计制造技术	All-digital high-end CNC equipment, all-digital AC servomotor, spindle motor and drive unit design and manufacturing technology
A60	高速、高刚度大功率电主轴及驱动装置设计制造技术	High-speed, high-rigidity, and high-power motor spindle and drive unit design and manufacturing technology
A61	大扭矩力矩电机及驱动装置设计制造技术	Large-torque torque motor and drive unit design and manufacturing technology
A62	大推力直线电机及驱动装置设计制造技术	Large-thrust linear motor and drive unit design and manufacturing technology

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A63	工程机械高压柱塞马达、液压泵、整体式多路换向阀设计制造技术	Construction machinery high-pressure piston motor, hydraulic pump, integrated multiple directional valve design and manufacturing technology
A64	大型工程机械驱动桥、动力换档变速箱设计制造技术	Large-scale construction machinery drive axle, power shift transmission design and manufacturing technology
A65	六自由度工业机器人设计制造技术	Six-degree-freedom industrial robot design and manufacturing technology
A66	工业机器人关键零部件设计制造技术（如减速器、控制系统等）	Industrial robot key component design and manufacturing technology (e.g. reducer, control systems, etc.)
A67	大型（下底板半周长度冲压模 > 2,500 mm，下底板半周长度型腔模 > 1,400 mm）、精密（冲压模精度 ≤ 0.02 mm、型腔模精度 ≤ 0.05 mm）模具设计与制造技术	Large-scale (lower plate stamping die half cycle > 2,500 mm, lower plate cavity die half cycle > 1,400 nm) and high-precision (stamping die precision ≤ 0.02 mm, cavity die precision ≤ 0.05 mm) mold design and manufacturing technology
A68	单套 10 万 m^3/h 以上空分装置用大型压缩机组设计制造技术	Large-scale single compressor used for greater than 100,000 m^3/h air separation design and manufacturing technology
A69	用于应急救援、极地科考、反恐、后勤保障的全地形、全天候、时速不小于 55 公里的履带式全地形系列工程车设计制造技术；8 吨以上、时速不小于 80 公里的多功能装载机设计制造技术	Crawler all-terrain vehicles used for emergency rescue, polar expeditions, anti-terrorism, and logistical support with speed greater than 55 km/h design and manufacturing technology; greater than 8 ton and greater than 80 km/h multi-functional loading machine design and manufacturing technology
A70	设施农业配套农机装备运用技术，包括播种、采摘等装备技术以及物联网应用技术	Agricultural machinery support equipment applied technology, including sowing and plucking equipment and IoT applied technology
A71	147 kW 以上大型拖拉机及配套农机具，110 kW 以上大马力自走式谷物联合收割机、青贮饲料收获机、番茄收获机，74 kW 以上自走式甘蔗和棉花收获机械设计制造技术	147 kW or above large tractor and supporting agricultural equipment, 110 kW or above high-powered self-propelled grain combined harvester, ensilage harvester, tomato harvester, 74 kW or above self-propelled sugarcane and cotton harvester design and manufacturing technology
A72	中高速(不低于 45 张/分钟)静电复印机和多功能一体机设计制造技术	Medium- and high-speed (45 sheets/min or above) xerographic printer and multifunction printer design and manufacturing technology
A73	电子测量仪器设计制造技术	Electronic measuring instrument design and manufacturing technology
A74	功率型、高亮度半导体发光二极管外延片、芯片设计制造技术，关键材料和设备设计制造技术	High power and brightness semiconductor light-emitting diodes wafer and chip design and manufacturing technology, key materials and equipment design and manufacturing technology
A75	新型电力电子器件、MEMS 设计制造技术	New-type power electronic device, MEMS design and manufacturing technology
A76	电子纸、触控显示面板新型显示器件制造技术	Electronic paper, touch control board and new-type display component design and manufacturing technology
A77	新能源及节能装备用高压电子元件设计制造技术	High-pressure electronic components for new energy and energy-saving design and manufacturing technology
A78	微型片式元件设计制造技术	Mini-type chip component design and manufacturing technology
A79	大型发电机组、大型石油化工装置、大型冶金成套设备等重大技术装备用分散型控制系统（DCS），现场总线控制系统（FCS），新能源发电控制系统开发及制造技术	Distributed control system (DCS), fieldbus control system (FCS), and new energy generator control system development and manufacturing technology used for major technology equipment (i.e. large-scale generator sets, petrochemical plants, metallurgical equipment sets, etc.)

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A80	汽车电子控制系统设计制造技术	Automotive electronic control systems design and manufacturing technology
A81	新能源汽车专用关键零部件设计制造技术	New-energy vehicle dedicated parts and components design and manufacturing technology
A82	混合动力汽车动力传动装置设计制造、配套标定技术	Power drive devices for hybrid electric vehicles design and manufacturing and supporting calibrating technology
A83	纯电动汽车无线充电技术	Wireless charging technology for pure electric vehicles
A84	插电式混合动力汽车开发设计制造技术	Plug-in hybrid electric vehicle development, design, and manufacturing technology
A85	汽车底盘电子控制系统设计制造技术（自动稳定杆系统、防抱死制动系统、车轨控制系统、电子稳定性控制系统、磁流控制悬架系统等）	Automobile chassis electronic control system design and manufacturing technology (automatic stabilizer bar systems, anti-lock braking systems, vehicle track control systems, electronic stability control systems, magnetic current controlled suspension systems, etc.)
A86	车身安全性设计分析技术	Automobile body security design and analysis techniques
A87	NVH 控制关键技术：风噪测试规范和评价技术，车型风噪优化技术，风噪数据模型，底盘系统振动噪声测试规范和评价技术，传动系统匹配建模和分析技术，变速器敲击噪声测试和评价技术，传动系统匹配参数数据模型等	Key technologies for NVH control (wind noise test specifications and evaluation technologies; car type wind noise optimization techniques; wind noise data model; chassis system vibration noise test specifications and evaluation technologies; transmission machine, modeling, and analysis techniques; gearbox knocking noise test and evaluation techniques; drive system matching parameter data model; etc.)
A88	先进自动变速器设计制造及控制系统开发技术（包括无级自动变速器，湿、干式双离合器自动变速器、重型车用电子机械自动变速器、七档及以上 AT 自动变速器等）	Design, manufacturing and development technologies of advanced automatic transmission and control systems (including the step-less automatic transmission; wet, dry-type dual-clutch automatic transmission; electro-mechanical automatic transmission for heavy-duty vehicles; seven-speed and above automatic transmission; etc.)
A89	整车 CAN 总线技术通讯协议建立、调试、诊断技术	Entire car CAN bus communication protocol building, debugging, and diagnostic techniques
A90	车身柔性焊装线设计制造技术	Car body flexible welding and assembly line design and manufacturing technology
A91	汽车空气动力学特性开发、测试和分析技术（如降风阻性能优化技术、汽车高速下的操纵稳定性和侧风稳定性优化技术、风噪优化技术、整车热管理优化技术、空气动力学测试规范和评价技术、空气动力学仿真分析技术、风洞标定技术等）	Automotive aerodynamic feature development, measurement, and analytical technology (i.e. wind reduction and performance optimization, auto handling stability improvement in high speed and crosswinds, wind noise optimization, vehicle thermal management, aerodynamics test regulation and assessment, aerodynamics simulation analysis, wind tunnel calibration, etc.)
A92	内燃机高压燃油喷射系统（压燃式内燃机用高压共轨系统，点燃式内燃机用缸内直喷供油系统）设计制造技术，可变进气系统设计制造技术，增压中冷（含复合增压和多级增压）技术	High-pressure engine fuel injection system design and manufacturing technology (compression ignition engine using high-pressure common rail system, spark ignition engine using in-cylinder direct injection fuel supply system), variable induction system design and manufacturing technology, intercooler technology (including composite supercharging and multistage supercharging technique)
A93	内燃机排放后处理系统设计制造技术	Internal combustion engine emissions after-treatment system manufacturing technology
A94	高速铁路、城际铁路及城市轨道交通关键运输装备的设计制造技术	High speed rail, intercity rail, and urban rail transportation equipment design and manufacturing technology
A95	高技术、高附加值、绿色环保与节能型船舶设计技术	High-tech, high-value-added, green environment protection and energy-saving ship design and manufacturing technology

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A96	大型远洋捕捞加工渔船、1 万立方米以上耙吸式挖泥船、火车渡轮、科学考察船、破冰船、海洋调查船、海洋监管船等特种船舶及其专用设备设计制造技术	Special purpose ship and dedicated equipment design and manufacturing technology (including large ocean-going fishing and processing vessels, 10,000 m^3 and above trailing suction hopper dredger, train ferry, research ship, icebreaker, marine research ship, inspection boat, etc.)
A97	船舶配套设备（包括船舶动力系统、电站、甲板机械、舱室机械、船舶控制及自动化、通讯导航、仪器仪表等）设计技术	Design technology of shipping support equipment (including ship dynamic systems, power stations, deck machinery, cabin machinery, ship control and automation, communications, navigation, instrumentation, etc.)
A98	海洋工程装备及配套设备设计制造技术	Marine engineering equipment and supporting equipment design and manufacturing technology
A99	游艇、高速艇和配套设备设计制造技术	Yachts, speedboats, and supporting equipment design and manufacturing technology
A100	修船（含改装船）设计技术	Ship repair (including ship modification) design and manufacturing technology
A101	三维声场计算技术	3D acoustic calculation technology
A102	航天和飞机研制相关设计制造技术	Aerospace and airplane-related research design and manufacturing technology
A103	大尺寸连续式跨音速风洞动力系统设计制造技术	Large-size, continuous, transonic wind tunnel aerodynamic system design and manufacturing technology
A104	光学材料超声铣磨加工技术	Optical material ultrasonic milling processing technology
A105	超高精度光学表面抛光技术	Ultra-precision optical surface polishing technology
A106	烟汽轮机、航空发动机转子零件冶金质量、力学性能控制和测试技术	Flue gas turbine and aero-engine rotor component metallurgy, mechanical property control and measurement technology
A107	航空、航天用重要合金材料返回利用技术	Key alloy material return and utilization technology for aviation and aerospace use
A108	模具混合浇注先进制造技术	Advanced mold mixed-pouring manufacturing technology
A109	轻量化材料应用技术：高强度钢、铝镁合金、复合塑料、粉末冶金、高强度复合纤维等；先进成形技术应用技术：激光拼焊板的扩大应用、内高压成形、超高强度钢板热成形、柔性滚压成形等；环保材料应用技术：水性涂料、无铅焊料等	Lightweight material application technology: high tensile steel, aluminum and magnesium alloy, composite plastic, powder metallurgy, high-strength composite fiber, etc.; advanced forming technology: extensive application of laser tailor-welded blanks, hydroforming, ultra-high-strength steel plate thermal forming, flexible roller forming, etc.; application technology of materials for environmental protection: water-based paint, lead-free solder, etc.
A110	产业用纺织品机械设计制造技术	Industrial use textile machinery design and manufacturing technology
A111	多维纺织成型技术及关键设备制造技术	Multi-dimensional textile forming technology and key equipment manufacturing technology
A112	高性能吸油纤维工程化关键技术和装备制造技术	Oil absorption fiber engineering and equipment manufacturing technology
A113	喷气涡流纺纱机设计制造技术	Air-jet vortex spinning design and manufacturing technology
A114	高性能苎麻纺织机械设计制造技术	High-performance ramie textile machinery design and manufacturing technology
A115	新型传感器制造技术	New-style sensor manufacturing technology

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A116	无线测控设备制造技术	Wireless monitoring and control equipment manufacturing technology
A117	高精度流量仪表制造技术	High-precision flow instrumentation manufacturing technology
A118	高档在线分析仪器设计制造技术	High-end online analytical instrumentation design and manufacturing technology
A119	在线精密测试仪器技术	Online precision testing instrument technology
A120	无损检测关键元器件制造技术	Manufacturing technology of NDT (non-destructive testing) key parts and components
A121	幅宽 6,000 mm 以上，车速 1,200 m/min 以上的先进造纸机械制造技术	Advanced paper-making machinery production technology of width of 6,000 mm or more, speed of 1,200 m/min or above
A122	高速精密平板切纸机设计制造技术	High-speed and high-precision tablet cutter design and manufacturing technology
A123	年产 15 万吨以上 APMP 高得率制浆生产线制造技术	High-yield pulp production line manufacturing technology for APMP (alkaline peroxide mechanical pulp) with more than 150,000 tons annual output
A124	无氯漂浆设备制造技术	Chlorine-free bleached pulp equipment manufacturing technology
A125	高效碱回收设备制造技术	High-efficiency alkali recovery equipment manufacturing technology
A126	生产能力达 72,000 瓶/时以上高速贴标机制造技术	High-speed labeling machine (capacity of 72,000 bottles/hour or more) manufacturing technology
A127	氢动力电池，锂离子电池高性能/低成本正极材料、高性能隔膜材料设计制造技术	High-performance and low-cost anode materials and diaphragms used for hydrogen batteries and lithium-ion batteries design and manufacturing technology
A128	定向分离与物性修饰生产技术	Directional isolation and physical properties modification production technology
A129	非热杀菌生产技术	Non-thermal sterilization production technology
A130	多级浓缩干燥生产技术	Multi-level enrichment drying production technology
A131	直接浸出炼锌技术	Direct leaching zinc technology
A132	单台炉直接炼铅技术（基夫塞特 Kivcet 炼铅技术）	Single furnace direct lead smelting technology (Kivcet lead smelting technology)
A133	非高炉炼铁技术	Non-blast furnace iron-making technology
A134	纯净钢冶炼技术	Pure steel smelting technology
A135	高温合金冶炼技术（温度区间在 900-1400°C）	Super alloy smelting technology (temperature range 900–1400°C)
A136	高强度汽车板、高牌号取向硅钢制造工艺技术	Process and manufacturing technology of high-strength steel sheets for automobiles, and high-grade oriented silicon steel
A137	放射性液体、固体废物先进处理工艺，具有高减容比的放射性废物处理先进技术，放射性事故应急处理技术，放射性沾污洗消技术	Radioactive liquid waste, solid waste, and radioactive waste with high-volume reduction ratio advanced disposal technology; radiation accident emergency handling technology; radioactive stain decontamination technology
A138	烧结机烟气脱硫、脱氮、脱二恶英等联合脱除技术	Integrated fume removal technology for sintering machines (including desulphurization, denitrification, and removing dioxin)
A139	焦炉煤气深加工利用技术	Further deep processing and utilization technologies of oven gases

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A140	炉渣余热回收利用技术	Slag waste heat recovery and utilization technologies
A141	超低温余热回收装置（ORC）及余热回收技术工艺包	Organic Rankine Cycle (ORC) and ultra-low-temperature waste heat recovery process and technology
A142	硫本系统 HRS 低温余热回收技术	HRS (heat recovery system) sulfur low-temperature waste heat recovery technology
A143	膜法和热法海水淡化技术	Membrane and heat desalination technology
A144	正渗透膜脱水技术	Osmosis membrane dehydration technology
A145	风力发电用及环保型环氧树脂生产技术	Environmentally-friendly epoxy resin production technology used in wind power generation
A146	用于电子级产品包装的加工设备及原材料技术	Processing equipment and raw material technologies used for packaging of electronic grade products
A147	GQ3522 以上碳纤维（简称 CF）成套装备的设计制造技术	GQ3522 and above carbon fiber (CF) complete set equipment design and manufacturing technology
A148	有机硅下游深加工产品生产技术	Deep processing of downstream organic silicon production technology
A149	年产 20 万吨以上过氧化氢催化氧化法、异丁烷共氧化法制环氧丙烷绿色成套技术	Set of sustainable green technologies for hydrogen peroxide as oxidants in catalytic oxidation, co-oxidation of isobutene for propylene oxide production (200,000 tons/year)
A150	百万吨级单线精对苯二甲酸（PTA）成套技术	Megaton singlet purified terephthalic acid (TPA) complete technology
A151	海盐发展盐钾溴镁联产、电水联产技术	Sea salt processing co-production technology of salt, potassium, bromine, and magnesium and power-desalting cogeneration technology
A152	离子膜烧碱淡盐水浓缩全卤制碱工艺技术	Ionic membrane caustic soda salt water concentrate technology of making alkali with bittern
A153	非光气法聚碳酸酯制造技术	Non-phosgene polycarbonate manufacturing technology
A154	高吸水性纤维生产技术	High absorbency fiber production technology
A155	无线辐射测试计量技术	Wireless radiation test measurement technology
A156	广播数字化及数字多媒体广播技术	Broadcast digital technology and digital multimedia broadcasting technology
A157	数字电视关键技术	Digital TV key technology
A158	搪塑镍合金电铸模具制造技术	Soft-nickel alloy electroforming die manufacturing technology
A159	纤维素乙醇生产技术	Cellulosic ethanol production technology
A160	聚乳酸纤维材料（简称 PLA）产业链成套装备的设计制造技术	Polylactic acid (PLA) fiber material complete set equipment design and manufacturing technology
A161	环保型新溶剂法纤维素纤维（即 LYOCELL、离子液等）成套装备的设计制造技术	New-style environmentally friendly solvent cellulose fibers (i.e., LYOCELL, ionic liquids, etc.) complete set equipment design and manufacturing technology
A162	新型聚酯 PTT 成套装备的设计制造技术	New-style polyester PTT (polytrimethylene terephthalate) complete set equipment design and manufacturing technology
A163	新型聚酯 PEN 成套装备的设计制造技术	New-style polyester PEN (polyethylene naphthalate) complete set equipment design and manufacturing technology

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A164	新型聚酯 PBT 成套装备的设计制造技术	New-style polyester PBT (polybutylene terephthalate) complete set equipment design and manufacturing technology
A165	高强高模芳纶 1414（学名聚对苯二甲酰对苯二胺，简称 PPTA）成套装备的设计制造技术	High-strength and high modulus aramid 1414 PPTA (p-phenylene-terephthalamide) complete set equipment design and manufacturing technology
A166	聚酰亚胺纤维及材料成套装备的设计制造技术	Polyimide fiber and materials complete set equipment design and manufacturing technology
A167	新型纺丝成网非织造布生产技术	New-style spunlaid non-woven production technology
A168	丙烷（R290）空调器技术	Propane (R290) air conditioner technology
A169	石墨深加工技术（大型节能高纯石墨装置关键制造技术）	Graphite processing technology (key manufacturing technology of large-scale, energy-efficient, and high-purity graphite equipment)
A170	高性能纤维产品设计制造技术	High-performance fiber production design and manufacturing technology
A171	静电纺丝技术	Electrospinning technology
A172	聚酰亚胺薄膜双向拉伸技术	Polyimide thin-film biaxial stretch technology
A173	PVA 混和浆中的 PVA 回收技术	Recovery technique of PVA (polyvinyl alcohol) from PVA blend pastes
A174	PAN 基碳纤维产业化原丝技术	PAN-based (polyacrylonitrile) carbon fiber industrialization precursor technology
A175	高浓度二氧化硫转化技术	High-concentration sulfur dioxide conversion technology
A176	高浓盐水处理技术	Concentrated brine processing technology
A177	年产 45 万吨以上丙烷脱氢制丙烯及配套压缩机技术	Production of more than 450,000 tons/year propane dehydrogenation for propylene and supporting compressor technologies
A178	年产 50 万吨以上丁烷分离异构成套技术	Set separation technology for production of more than 500,000 tons/year butane isomer
A179	丙烷制冷压缩机技术	Propane refrigeration and compressor technology
A180	保障农产品加工质量安全、提高产品市场竞争力的清洁生产和环境污染控制制造技术	Cleaner production and pollution control manufacturing technology to protect the quality and safety of agricultural products and improve product market competition
A181	高效低残留农药使用技术（包括生物防治技术）	High-performance, low-residue agricultural pesticide drug use technology (including biological control technology)
A182	农产品、食品中有毒有害物质（包括农药、兽药、重金属、添加剂等）残留控制与检测技术	Toxic and harmful substances residue control and detection technology for agricultural products and food (including pesticides, veterinary drugs, heavy metals, additives, etc.)
A183	农产品质量安全追溯技术	Agricultural product quality and safety retrospective technology
A184	农产品质量安全风险评估技术（包括模型、数据等）	Agricultural product quality and safety risk assessment techniques (including models, data, etc.)
A185	良好农业规范（GAP）、危害分析与关键控制技术（HACCP）、农产品良好检测实验室管理技术	Good agricultural practices (GAP), hazard analysis and critical control process (HACCP), good agricultural product inspection laboratory management and technology
A186	动植物优良品种选育、繁育、保种和开发技术	Animal and plant breeding of fine varieties, breeding, species preservation and development technology

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A187	旱作节水农业、保护性耕作、连作障碍土壤修复、生态农业建设、耕地质量建设以及新开耕地快速培肥技术	Dry farming water-saving agriculture, conservative farming, continuous cropping obstacles restoration, ecological agriculture construction, land quality construction as well as new developed farmland rapid fertility technologies
A188	动物传染性海绵状脑病快速检测技术	Rapid detection technology for animal transmissible spongiform encephalopathies
A189	奶牛乳房炎防控技术	Cow mastitis prevention and control technology
A190	饲料霉变程度及霉菌毒素快速检测技术	Moldy feed level and rapid detection of mycotoxins
A191	外来动物疫病监控技术	Foreign animal disease monitoring technology
A192	蜜蜂抗螨育种技术	Anti-mite bee breeding techniques
A193	马属动物传染病检疫检验技术	Equine animals infectious diseases inspection and quarantine technology
A194	美国玉米雄性核不育制种（SPT）技术	US maize male sterility seed production technology (SPT)
A195	食品蛋白质组学技术	Food proteomics technology
A196	高温瞬时双峰杀菌技术	High-temperature doublet sterilization technology
A197	临界流体辅助压榨技术	Supercritical fluid-assisted squeezing technology
A198	肉类食品营养保持和强化技术	Meat nutrition maintenance and enhancing technology
A199	水产蛋白抗冷冻变性及改性技术	Antifreeze aquatic protein degeneration and modification technology
A200	南极磷虾捕捞和即时加工技术	Antarctic krill fishing and instantaneous processing technology
A201	动物疫病的新型诊断试剂、疫苗及低毒低残留新药开发技术	Development technologies of new animal disease diagnostic reagents, vaccines, and drugs with low-toxicity residue
A202	建筑垃圾处理和再生利用工艺成套设备制造技术	Construction waste disposal and recycling processes complete set equipment manufacturing technology
A203	符合环保要求的废旧电池回收处理工艺与装备技术	Waste battery recycling technology and equipment technology in line with environmental requirements
A204	电子废弃物干式分离回收技术	E-waste dry-type separation and recovery technology
A205	化学纤维的清洁生产和环境污染控制技术	Chemical fiber clean production and environment pollution control technology
A206	废旧纺织品再利用制造技术	Waste textiles recycle and manufacturing technology
A207	废玻璃自动分色分选技术	Waste glass automatic color separation and sorting technology
A208	含汞照明器具无害化回收利用技术	Mercury illuminator harmless recycling and utilization technology
A209	二恶英污染防治技术	Dioxin pollution prevention technology
A210	有毒、有机废气、恶臭处理技术	Toxic substance, organic flue gas, and odor disposal technology
A211	废弃滤袋处理处置技术	Abandoned filter bag processing and disposal technology
A212	重金属污染防治技术	Heavy metal pollution prevention technology
A213	高浓度难降解有机工业废水深度处理技术	Advanced waste treatment of high-concentration and hard-degradable organic industrial wastewater

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A214	有色金属工业废水处理循环利用系统技术	Non-ferrous metallurgy industrial wastewater disposal and recycle system technology
A215	废旧塑料分选技术	Waste plastic sorting technology
A216	市政污泥处置技术	Municipal sludge disposal technology
A217	城镇污水处理设施总磷、总氮深度处理技术	Total phosphorus and total nitrogen advanced treatment technology for municipal sewage disposal facilities
A218	畜禽养殖业排泄物资源化综合利用技术	Resource-integrated utilization technology for livestock industry excrement
A219	冶金固体废弃物（含冶金矿山废石、尾矿，钢铁厂产生的各类尘、泥、渣、铁皮等）综合利用先进工艺技术	Metallurgy solid waste (including metallurgy mining waste rock, tailings, and dust, sludge, slag, iron sheet, etc.) advanced integrated utilization technology
A220	焦炉、高炉喷吹废旧塑料、橡胶产品技术	Coke oven and blast furnace-blowing waste plastic and rubber products technology
A221	二氧化碳回收利用技术	Carbon dioxide recycling technology
A222	大气和烟气重金属污染在线监测技术及其设备和关键元器件制造技术	Online monitoring technology and equipment and key components manufacturing technology of atmosphere and flue gas polluted by heavy metal
A223	烧结机烟气脱硫副产物资源化、再利用技术	Resource-made and reutilization technology of sintering machine flue gas desulfurization by-product
A224	物流高速分拣设备系统技术	Logistical high-speed sorting equipment system technology
A225	物流中心智能高效的自动包装技术	Logistical center smart and efficient automatic packaging technology
A226	物流行业专业电子地图开发技术	Logistical industry professional electronic map development technology
A227	垂直货物运输系统技术	Vertical goods transportation system techniques
A228	低汞型高效照明产品制造技术	Low mercury efficient lighting product manufacturing technology
A229	高效换热器、蓄能器设计制造技术	Heat-efficient exchanger and energy-preserving design and manufacturing technology
A230	环保型废电器电子稀贵金属提纯还原技术	Environmentally-friendly purification and reduction technology for electrical and electronic equipment waste and rare/expensive metals
A231	玻璃瓶罐轻量化生产技术	Glass container lightweight production technology
A232	耐热微晶玻璃餐具生产技术	Heat-resistant crystal glass container production technology
A233	连续纤维增强热塑性复合材料制造技术	Continuous filament and reinforced thermoplastics composite materials manufacturing technology
A234	二氧化碳热泵热水器技术	Carbon dioxide pump water heater technology
A235	航空航天用高性能铝合金、钛合金制造技术	Manufacturing technology for high-performance aluminum and titanium alloys used for aerospace
A236	钽铌高温合金及其涂层制造技术（使用温度>1360 °C）	High-temperature tantalum niobium alloy and coating manufacturing technology (service temperature: > 1360 °C)
A237	高性能铟锡耙材制造技术	Manufacturing technology for high-performance indium and tin targets
A238	高性能硬质合金制造技术	High-performance hard alloy manufacturing technology

Advanced Technology Encouraged Imports 鼓励引进的先进技术 (continued)

No.	Technology (Chinese)	Technology (English)
A239	大功率激光制造技术	High-power laser manufacturing technology
A240	化学气相沉积钨制品（CVD-W）技术（制品及涂层纯度 ≥ 99.999%，孔隙度 ≤ 1%，高致密度>19.2 g/cm^3，高温（1,000 °C）弯曲强度>1,000 Mpa，特定晶体取向，低内应力，高温使用不易挥发）	Chemical vapor deposition tungsten production technology (CVE-W): the purity of product and coating ≥ 99.999%, porosity ≤ 1%, high-density > 19.2 g/cm^3, high-temperature (1000 °C) bending strength > 1,000 Mpa, specific crystal-orientated, low-internal stress and low volatility at high temperatures
A241	超导磁场拉晶技术	Superconducting magnetic field crystal pulling technology
A242	大型往复式客运索道（100 人以上车厢）关键设备的设计制造技术	Key equipment of large reciprocating passenger ropeway (capacity of 100 passengers or more) design and manufacturing technology
A243	新型双承载单牵引循环脱挂式客运索道（3S 索道）设计制造技术	Design and manufacturing technology of new-style two-cable carry and single-traction cycling and detachable passenger ropeway (3S ropeway)

Important Equipment Encouraged Imports 鼓励进口的重要装备

No.	Product No.	Product (Chinese)	Product (English)
B1	845710	镗铣加工中心：1) 工作台宽度 ≤ 630 mm 的镗铣加工中心：≥ 4 轴联动；快移速度 > 60 m/min，重复定位精度 < 0.0025 mm；2) 630 mm<工作台宽度 ≤ 1250 mm 的镗铣加工中心：≥ 4 轴联动；快移速度 > 40 m/min，重复定位精度 < 0.003 mm；3) 工作台宽度 > 1250 mm 的镗铣加工中心：≥ 4 轴联动；快移速度 > 20 m/min, 重复定位精度 < 0.004 mm	Boring and milling machining center: 1) boring and milling machining center with worktable width ≤ 630 mm: four-axis linkage or above; fast motion speed > 60 m/min, repetitive positioning accuracy of < 0.0025 mm; 2) boring and milling machining center with worktable width > 630mm and < 1250mm: four-axis linkage or above; fast motion speed > 40m/min, repetitive positioning accuracy of < 0.003mm; 3) boring and milling machining center with worktable width ≥ 1250 mm: four-axis linkage or above; fast motion speed > 20 m/min, repetitive positioning accuracy of <0.004 mm
B2	845710	柔性加工单元：5 轴联动	Flexible machining cell: 5-axis linkage
B3	84581100 84589100	车削中心：重复定位精度 < 0.002 mm，主轴端径向圆跳动 < 0.0005 mm，加工圆度 ≤$4×10^{-6}$ × D mm（D 为最大加工工件直径）	Turning center: repeat positioning accuracy < 0.002 mm, spindle-side radial runout < 0.0005mm, workpiece roundness ≤ 4 ×10^{-6} × D mm (D denotes the diameter of maximum workpiece)
B4	84601100 84602190	数控平面磨床（含成形、龙门、导轨、双端面等）：定位精度 ≤ 0.003 mm/2,000 mm，重复定位精度 ≤ 0.0015 mm/2,000 mm，龙门宽 > 3,500 mm，平面度 ≤ 0.003 mm/3,000 mm	Computer numerical control (CNC) surface grinding machine (including the shape, gantry, rail, double-end, etc.): positioning accuracy ≤ 0.003 mm/2,000 mm, repeated positioning accuracy ≤ 0.0015 mm/2,000 mm, gantry width > 3,500 mm, flatness ≤ 0.003 mm/ 3,000 mm
B5	84602110 84602120 84602910 84603100	数控磨床（含内圆、外圆、端面外圆、万能、无心、轴承、专用等）：定位精度 ≤0.004 mm，重复定位精度 ≤ 0.002 mm，加工圆度 ≤ 3 × 10^{-6} × D mm（D 为最大加工工件直径），砂轮线速度>60m/s；刃磨：主轴转速 10,000 r/min，重复定位精度直线轴 ≤ 0.002 mm，回转轴 ≤ 0.002°，多轴控制五轴联动；坐标磨床：四轴四联动、七轴四联动	CNC grinding machine (including inner circle, outer circle, end face outer circle, universal, coreless, bearing, blade grinding, dedicated, etc.): positioning accuracy ≤ .004 mm, repeated positioning accuracy ≤ 0.002 mm, workpiece roundness ≤ 3 × 10^{-6} × D mm (D denotes the diameter of the maximum workpiece), grinding wheel linear speed > 60 m/s; cutter sharpening: principal axis speed = 10,000 r/min, repeated positioning accuracy of line axis ≤ 0.002 mm, rotor ≤ 0.002°, multi-axis control 5-axis linkage; coordinate grinder: 4-axis with 4 linkages, 7-axis with 4 linkages
B6	84596110	数控龙门铣床：工作台宽度 ≥ 5,000 mm，重复定位精度 < 0.006 mm/2,000 mm，≥ 4 轴联动	CNC gantry milling machine: workbench width ≥ 5,000 mm, repeated positioning accuracy ≤ 0.006 mm/2,000 mm, four-axis linkage or above
B7	84604010	数控珩磨机床（不含深孔珩磨机床）：孔径圆度 ≤ 0.002 mm，孔的直线度 ≤ 0.002 mm/200 mm，珩孔表面粗糙度 Ra < 0.05 μm	CNC honing machine (excluding deep hole honing machine): aperture roundness ≤ 0.002 mm, hole straightness ≤ 0.002 mm/200 mm, hole surface roughness Ra < 0.05 μm
B8	84639000	数控曲轴圆角深滚压和滚压校直机床：滚压数 ≥ 6，滚压力 ≥ 30,000N	CNC crankshaft deep fillet rolling and rolling alignment machine: roll number ≥ 6, roll pressure ≥ 30,000 N
B9	84602110 84602120 84602190	数控重型磨床：D > 2,500mm，微量进给 ≤ 0.0001 mm，重复定位精度 ≤ 0.005 mm，加工圆度 < 3 × 10^{-6} × D mm（D 为最大加工工件直径）	CNC heavy-duty grinder: workpiece diameter > 2,500 mm, micro feed ≤ 0.0001 mm, repeated positioning accuracy ≤ 0.005 mm, workpiece roundness < 3 × 10^{-6} × D mm (D denotes the diameter of the maximum workpiece)
B10	84171000	多膛焙烧炉（氧化钼）	Multiple hearth furnace (molybdenum oxide)
B11	84629910	精锻机（钼）	Precision forging machine (molybdenum)
B12	8514 84171000	金属注射成型脱脂烧结炉	Metal injection mold degrease sintering furnace

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B13	841790 84798190	自动剥锌机	Automatic zinc stripping machine
B14		铜冶炼无种板精炼工艺及装备	No starting sheet copper smelting refining processes and equipment
B15		大直径高沉积效率单模光纤预制棒成套装备：沉积速度 ≥ 100 g/min，沉积效率 ≥ 60%，预制棒直径 ≥ 150 mm	Complete set equipment of large-diameter and high-deposition rate single mode fiber performing rod: deposition speed ≥ 100 g/min, deposition rate ≥ 60%, performing rod diameter ≥ 150 mm
B16	8417 8514 8419 8421 84223030 84798200	年产 10 万吨以上氯化法钛白生产关键设备（氯化炉、$TiCl_4$ 预热器、氧化预热器、$AlCl_3$ 发生器、氧化反应器、氯化炉排渣设备、螺杆气力输送泵、超微气流粉碎机、大型立式隔膜压滤机、大型闪蒸干燥设备、全自动包装机、耐腐蚀泵等）	Key equipment of chloride process titanium dioxide production (annual output > 100,000 tons): chlorination furnace, $TiCl_4$ preheater, oxidation preheater, $AlCl_3$ generator, oxidation reactor, chlorination furnace slag extractor, screw strength delivery pump, ultra-micro airflow mill, large-size vertical membrane filter press, large size flash dryer equipment, automatic packaging machine, anti-corrosion pump, etc.
B17	85141010	水平和立式展开式保护气体退火机列	Horizontal and vertical expansion-type protective gas annealing machine lines
B18	84791090	高等级公路稀浆封层机：料仓 > 10 m^3，制浆 > 3 t	Superhighway slurry seal machine: hopper > 10 m^3, pulping > 3 t
B19	84201000	砑光机或其他滚压机器	Calendering or other rolling machines
B20	84798200	船用混油装置：除最高粘度 ≤ 7×10^{-4} sec（rwl#100 度 F）的动态恒压混合方式	Marine oil decontamination devices: maximum decontamination viscosity of 7×10^{-4} sec (rwl#100 °F) dynamic constant-pressure mix
B21	84795010	大型作业水下机器人：工作深度 > 300 m，最大埋设缆直径 ≥ 300 mm	Large-scale operation project underwater robot: working depth >300 m, maximum diameter of burying cable ≥ 300mm
B22	8479820090	研磨机：研磨能力 > 26,000 kg/h，进口粒度 ＜ 25 μm，出口粒度 ＜ 16 μm	Grinding machines: grinding capacity > 26,000 kg/h, input grain size < 25 μm, output grain size < 16 μm
B23	90262010	轨道检查车用传感器	Sensors for track inspection vehicles
B24	84082010 84122910 84135031 84812010 87087010 87089910 85371011	履带式全地形工程车（满载质量 ≥ 13,000 kg，最高公路行驶速度 ≥ 60 km/h）制造用关键零部件：柴油机（额定功率 ≥ 224 kW），液压马达，液压阀，液压泵，行走系统总成（行驶速度 ≥ 50 km/h），可编程控制器总成（高抗震性，耐高温 100 °C 以上）	Crawler all-terrain truck (maximum weight ≥ 13000kg, maximum running speed ≥ 60km/h) manufacturing-used key components: diesel engine (rated power ≥ 224 kW), hydraulic motor, hydraulic valve, hydraulic pump, walking system assembly (speed ≥ 50 km/h), plannable controller assembly (high shake resistant, high temperature resistant: 100 °C or more)
B25		机器人智能焊接生产线关键设备	Key equipment for intelligent robotics welding production line
B26	87085071 87084010 84138200	14 7 kW 以上轮式拖拉机前驱动桥总成、液压提升器	147 kW or greater wheeled tractor, front-drive axle assembly and hydraulic lifting device
B27	84339010	自走式青贮饲料收获机圆盘割台	Disc cutting table for self-propelled silage harvesters
B28	84368000	大田玉米制种去雄机	Field corn seed emasculation machines
B29	8432303100	大田水稻制种插秧机	Daejeon rice seed transplanter
B30	8433	大型牧草收割机（割幅 4.5m 以上）	Large-scale herbage reaper (reap width: 4.5 meters or greater)

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B31		单核苷酸多态性（single nucleotide polymorphism，SNP）高通量检测平台	Single nucleotide polymorphism (SNP) high-throughput inspection platform
B32	9024	高温硬度仪：最高测量温度 ≥ 1,200 °C，真空度 ≤ 10 × 10^{-5}托	High-temperature hardness tester: maximum measurement temperature ≥ 1200 °C, vacuum degree ≤ 10 × 10^{-5} torr
B33		电子束熔化炉：功率 ≥ 500 kW，能在 1,200 °C 以上的熔化温度工作	Electron beam melting furnace: power ≥ 500 kW, able to work at melting temperature (1,200 °C or more)
B34		喷气燃料热氧化安定试验机（JFTOT）：双头 HPLC 泵，无限燃料样本容量，加热器管温度设定范围 100 °C 至 380 °C，燃料样品流速范围 0.001 ml/min 至 9.999 ml/min，流速精确率高于 ± 2%	Jet fuel thermal oxidation stability tester (JFTOT): Dual-head HPLC pump, unlimited fuel sample capacity, temperature setting range of heater: 100 °C–380 °C, fuel sample velocity range: 0.001 ml/min–9.999 ml/min, velocity accuracy rate > ± 2%
B35		快速大变形的应变与温度双通道传感器及其测试装置：压力范围为-1（拉）~+20（压）MPa；温度量程为-20 °C~+60 °C；测试灵敏度的应力测试优于 0.01 MPa，温度测试优于 0.1 °C；动态指标的应力时滞低于 0.01 s，温度时滞低于 0.1 s	Response to rapid deformation and temperature two-channel sensor and testing device: pressure range: -1 (pull) to +20 (press) MPa; temperature measuring range: -20°C to +60°C; stress test of measurement sensitivity superior to 0.01 MPa, temperature test superior to 0.1 °C; stress time lag of dynamic indicator ≥ 0.01 s, temperature time lag ≥ 0.1 s
B36	90312000 90318090	大型多台并激振动试验系统：推力 ≥ 150 t	Large-size, multi-vibration testing system: thrust ≥ 150 t
B37		大型超高强度钢变壁厚高精度封头精密成形装备：吨位 ≥ 70 t，加工范围为 1,500–3,500 mm，钢板厚 ≥ 18 mm	Large-scale, ultra-high-strength steel, variable wall thickness and high-precision head forming equipment: tonnage ≥ 70 t, machining range: 1,500–3,500 mm, steel thickness ≥ 18 mm
B38	90248000 90278099	流变仪：温度范围：室温~400 °C ± 1 °C；升温速率：1，2，3，4，6 °C/min，连续可调，并可快速升温；测温精度：计算机显示 < ± 0.5 °C，分辨率：0.1 °C；压力范围：1~50 MPa ± 1%；毛细管规格: (直径×长度) ⊄1 × 5 ⊄1 × 10 ⊄1 × 20 ⊄1 × 40	Rheometer: temperature range: room temperature 400 °C ± 1 °C; heating rate: 1, 2, 3, 4, 6 °C/min, can be continuous adjustable and rapid heating; accuracy of temperature measurement: computer display < ± 0.5 °C, resolution rate: 0.1 °C; pressure range: 1–50 MPa ± 1%; capillary specification: (diameter × length) ⊄1 × 5 ⊄1 × 10 ⊄1 × 20 ⊄1 × 40
B39	90275000 90314990	MS3000 激光粒度分析仪：测试范围为 0.02~3,500 μm，准确度优于+/-1%，重复性优于+/-0.5%，重现性优于+/-1%，原理为激光衍射	MS3000 laser particle sizer: measurement range: 0.02–3,500 μm, accuracy superior to +/-1%, repeatability is superior to +/-0.5%, reproducibility is superior to +/-1%, laser diffraction as principal
B40	8444	高强高模芳纶 1414（聚对苯二甲酰对苯二胺，简称 PPTA）关键装备及零部件（包括聚合、纺丝、后加工技术等）	High-strength and high modulus aramid 1414 (formal name p-phenylene terephthalamide, referred to as PPTA) key equipment and components (including polymerization, spinning, post-processing techniques, etc.)
B41		10 万吨/年聚碳酸酯生产关键设备（聚结分离器，干燥系统，挤出造粒系统）	Key equipment of 100,000-ton-annual-output polycarbonate manufacturing (coalescing separator, drying system, extruding and granulating systems)
B42	8444	GQ3522 以上碳纤维及其制品（简称 CF）关键装备	GQ3522 and above carbon fiber (CF) key equipment
B43	8444	聚酰亚胺纤维成套装备（包括以 P84 为代表品种的各类纤维）、聚酰亚胺薄膜双向拉伸成套装备	Polyimide fiber complete set equipment (including all kinds of fiber, represented by P84), polyimide thin-film biaxial stretch complete set equipment
B44	84451120	毛型纤维梳理机	Wool-type fiber carding machine

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B45	84452031	转杯纺纱机: 纺杯最高速度>170,000 r/min，可自动生头、接头、清洁提升	Rotor spinning machine: the highest speed spinning cup > 170,000 r/min, with automatic hygiene head, joints, cleanness enhancement
B46	84452032	喷气纺纱机：纺纱速度>300m/min	Air-jet spinning machine: spinning speed of > 300 m/min
B47	84463090	刚性剑杆织机、片梭织机、双层织物织机、宽幅重磅织机等特种无梭织机	Special shuttleless loom such as rigid rapier loom, gripper loom, double-layer loom, wide and heavy loom, etc.
B48	84472020	全成型编织横机	Seamless-wear flatbed knitting machine
B49	84514000	针织连续前处理和冷轧堆染色机生产线	Knitting continuous pretreatment and cold pad batch dyeing machine production line
B50	84454010	松式筒子自动络筒机：卷绕速度 ≥ 1,000 m/min；细络联型及全自动托盘型自动络筒机：卷绕速度 ≥ 2,200 m/min	Pine cone automatic winding machine: winding speed ≥ 1,000 m/min; fine network-linked and fully automatic tray type winding machine: winding speed ≥ 2,200 m/min
B51	8449	特种非织造布制造或整理机器：10 g/m^2 以下的薄型涤纶纺粘非织造布生产设备，400 g/m^2 以上的丙纶厚型纺粘非织造布生产设备，宽幅高速纺粘熔喷非织造布生产设备（幅宽 ≥ 4 m；速度 ≥ 600 m/min)，高压水刺生产设备（幅宽 ≥ 3.5 m，水刺压力 ≥ 40 MPa）	Special non-woven manufacturing and adjustment machine: 10 g/m^2 or less thin polyethylene terephthalate manufacturing equipment, 400 g/m^2 or more thick polypropylene terephthalate manufacturing equipment, wide and high-speed, spun-bonded, melt-blown, non-woven manufacturing equipment (width ≥ 4 m; speed ≥ 600 m/min), high-spunlace pressure equipment (width ≥ 3.5 m, spunlace pressure ≥ 40 MPa)
B52	84459090	全自动穿综机	Fully automatic drafting machines
B53	84513000	熨烫机及挤压机（包括熔压机）	Ironing machines and extrusion machines (including melting presses)
B54	84451220	毛精梳机	Worsted card
B55	84451310	针梳机：速度 ≥ 200 m/min	Gilling machine: speed ≥ 200 m/min
B56	84451322	毛粗纱机：搓捻速度 ≥ 1,500 次/min	Worsted roving frame: bunching speed ≥ 1,500 movements/min
B57	84452042	毛纺环锭细纱机（配紧密纺装置）	Ring spinning frames for woolen spinning machine (equipped with compact spinning device)
B58	84490000	产业用纺织品多功能后整理线/设备	Industrial-use multi-functional fabric finishing line and equipment
B59	84518000	纺织品多功能后整理线/设备(含整理机、定型机、洗煮烘联合机、罐蒸机、剪呢机、平幅洗呢机）	Textile multi-functional fabric finishing line and equipment (including treating machine, setting machine, washing-cooking-drying all-in-one machine, pot decatizing machine, cutter and open-width washer)
B60		废旧纺织品分拣设备：可智能识别纤维成分比例，工作效率 3 件/s 以上；高效湿法废纺开松设备	Waste textile sorting equipment: capable of identifying fiber composition intelligently; efficiency: 3 items/s or more; high-efficiency waste textile opening equipment
B61	84391000	纸浆生产的大型机器：年产 30 万吨以上化学浆生产设备；年产 10 万吨以上化机浆生产设备	Large pulp production machines: chemical pulp production equipment with an annual output of 300,000 tons or more; mechanical pulp production equipment with an annual output of 100,000 tons or more
B62	84392000	浆板机：幅宽 ≥ 8,000mm，工作车速≥ 300 m/min	Pulp plate machine: width ≥ 8,000 mm, working speed ≥ 300 m/min
B63	84392000 84393000	造纸机：幅宽 ≥ 7,000 mm，工作车速 ≥ 1,500 m/min	Paper machines: width ≥ 7,000 mm, working speed ≥1,500 m/min

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B64	84392000	年产 30 万吨以上纸板生产机器	Cardboard production machine products (annual output >300,000 tons)
B65	84414000	纸浆、纸或纸板制品模制成型机器	Pulp, paper, or cardboard products molding machines
B66		制革及毛皮加工工业污泥减量化处理或再利用设备	Sludge-reducing process and reutilization equipment for the tanning and fur manufacturing industry
B67	8422309090	缩颈翻边封口一体机：速度 800 罐/分	Necking, curling, and sealing all-in-one machine (speed: 800 items/min)
B68		滚筒式智能化 TMR 搅拌车：负载能力为 1,500 kg–10,000 kg，动力输出轴功率为 17 kW/40 hp–90 kW/120 hp，规格为 MF210 (5 m³)–MF400 (28 m³)	Drum-type intelligent TMR agitating lorry: load capacity 1,500–10,000 kg, power output 17 kW/40 hp–90 kW/120 hp, specification MF210 (5 m³)–MF400 (28 m³)
B69	8462101000	全自动多模冲床：高速底盖生产线上的装备之一；13 个模头，最大速度 2,925 个/分	Fully automatic multimode punch: 13 grinding heads, maximum speed 2,925 items/min
B70	9027809900	饮料产品含氧量在线检测设备：测量范围 0~20.0ppm；饱和度:（-10 到 80 °C 时） 0 到 200%；测量精度：±0.5% FS；分辨率：0.01%；介质温度范围：-5~140 °C；介质压力： ≤ 6 bar；最大压力：12 bar	Online oxygen detector for beverages: measurement range 0–20.0 ppm; saturation 0–200% when temperature is -10 °C–80 °C; accuracy of measurement ± 0.5% FS; resolution ratio ± 0.01%; medium temperature range -5–140 °C; medium pressure ≤ 6 bar; maximum pressure 12 bar
B71	8418	液氮冷冻机	Liquid nitrogen refrigerators
B72	84431100	报纸用卷筒纸胶印机：单幅机印刷速度 > 75,000 对开张/小时，幅宽 ≥ 787 mm；双幅机印刷速度 > 150,000 对开张/小时，幅宽 ≥ 1,562 mm	Web offset printing equipment for newspapers: printing speed for single-width machines 75,000 pairs of open/hour, width ≥ 787 mm; for double-width machines150,000 pairs of open/hour, width ≥ 1,562 mm
B73	84431200 844313	单张纸胶印机：对开单张纸单面多色胶印机速度 > 18,000 张/小时，纸张尺寸≥750 × 1060 mm；对开单张纸双面多色胶印机速度 > 15,000 张/小时，纸张尺寸 ≥ 720 × 1030 mm；全张及超全张单张纸单面多色胶印机速度>13,000 张/小时，纸张尺寸 ≥ 1,000 × 1,400 mm；上述均为四色及四色以上	Sheet-fed offset presses: single-sided, multi-color sheet-fed offset press with speeds of 18,000 sheets/hour, paper size ≥ 750 x 1,060 mm; double-sided multi-color sheet-fed offset press with speeds of > 15,000 sheets/hour, paper size ≥ 720 x 1,030 mm; single-sided multi-color sheet-fed offset press for souvenir sheets and ultra-sheet with speeds of 13,000 sheets/hour, paper size ≥ 1,000 x 1,400 mm; above mentioned presses are all four-color or more
B74	844130 844140 844180	瓦楞板生产设备：速度>300 m/min，板宽 > 2.5 m，七层以上	Corrugated board production equipment: speed > 300 m/min, width > 2.5 m, more than seven layers
B75	8444	氟聚合物聚合反应器及后处理关键设备、挤出加工设备：包括微米级粉碎、高效洗涤、脱水、 连续干燥、 挤膜、 1600mm 以上双向拉伸、 浸渍、 烘烤等	Fluoropolymer polymerization reactor and post-processing key extrusion processing equipment (including micron grinding, high-efficiency washing, dehydration, continuous drying, squeeze film, 1,600 mm or more two-way stretch, dipping, baking, etc.)
B76	90248000	聚合物序列结构测试表征仪器	Polymer sequence structural testing characterization instrumentation
B77		高浓盐水处理设备	Concentrated brine processing equipment

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B78		低浓度难降解有机废水深度臭氧催化氧化成套设备（进水水质：COD：80 mg/L~120 mg/L，苯并芘：0.1 μg/L~5 μg/L，多环芳烃：0.1 mg/L~10 mg/L；出水水质：COD 平均去除率 > 50%，苯并芘平均去除率 90%~99%，多环芳烃平均去除率 90%~99%；处理能力 25 t/h~1,000 t/h）	Low-concentration and hard-organic wastewater deep-ozone catalytic oxidation complete set equipment (inflow water quality: COD 80 mg/L–120 mg/L, benzopyrene 0.1 μg/L–5 μg/L, PAHs 0.1 mg/L–10 mg/L; outflow water quality: average COD removal rate > 50%, average benzopyrene removal rate 90%–99%, average PAHs removal rate 90%–99%; processing capability 25 t/h–1,000 t/h)
B79		高浓度氨氮废水资源化处理成套设备（原水水质：氨氮浓度 ≤ 80 g/L，处理水质：氨氮 ≤ 10 mg/L，废水中氨氮资源化回收制备高纯浓氨水>16%，污染物削减率 > 99%，氨氮资源回收率 > 99%，回收的氨水可以达到试剂级以上）	High-concentration ammonia waste water resource-made complete set equipment (raw water quality: ammonia concentration ≤ 80 g/L; processed water quality: ammonia ≤ 10mg/L; high-purity concentrated ammonia in recycling and resource-made wastewater > 16%, pollutant reduction rate > 99%, ammonia resource recycling rate > 99%, recycled ammonia water can reach reagent level or above)
B80	84193990	分散聚四氟乙烯连续密闭式干燥设备	Continuous closed drying equipment for dispersion polymerized polytetrafluoroethylene resin
B81	38011000	高温碳化炉用人造石墨板、石墨保温硬毡	Delanium board used in high-temperature carbide furnaces, graphite hard felt for heat preservation
B82	84335920	采棉机用采棉头	Cotton-picking heads
B83	8461 8463 8475	陶瓷金属卤化物灯生产设备	Ceramic metal halide lamp production equipment
B84	90221910	低剂量 X 射线安全检查设备：X 射线发生器管电压 > 420 kV	Low-dose X-ray security screening equipment: X-ray generator tube voltage > 420 kV
B85	90272020	电泳仪：电源电压 > 1,000 V	Electrophoresis apparatus: power supply voltage > 1,000 V
B86	90278019	质谱联用仪：液相色谱质谱联用仪、二级以上气相色谱质谱联用仪	Chromatograph mass spectrometer: liquid chromatograph mass spectrometer, second class or above gas chromatograph mass spectrometer
B87	90158000	地震仪：25,000 道以上，24BIT	Seismograph: 25,000 channels and above, 24-bit
B88	90158000	磁力仪：测量范围 25000–80000 nT，测量精度 ± 0.2 nT，分辨率 0.02 nT，梯度范围 5,000 nT/m，存贮数据 25,000 个以上读数	Magnetometer: measurement range 25,000–80,000 nT, measuring accuracy ± 0.2 nT, resolution 0.02 nT, gradient range 5,000 nT/m, data storage for more than 25,000 readings
B89		碳化硅半导体单晶生长和加工设备	Carborundum semiconductor monocrystal growth and processing equipment
B90	9012 90314100	制造半导体器件时检验半导体晶片、元器件或检测光掩模及光栅用的光学仪器	Semiconductor wafers and components for semiconductor device inspection or optical instruments to detect photomask and grating in semiconductor manufacturing process
B91	8486	光刻机、刻蚀机、气相沉淀、离子注入、金属沉淀等集成电路芯片制造设备	Integrated circuit chip manufacturing equipment for lithography machines, etchers, vapor deposition, ion implantation, metal deposition, etc.
B92	84863	TFT-LCD、OLED 面板生产用专用设备和仪器	TFT-LCD, OLED board production

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B93		MEMS 器件、片式元件、新型电力电子器件、半导体照明等专用设备	Special devices such as MEMS components, chip components, new-type electrical and electronic components, semiconductor lighting, etc.
B94	90262090 90272019	致密岩石渗透率测试仪器：测试精度 10-3-10-9md	Compact rock permeability tester: accuracy of testing 10-3–10-9 md
B95	90318090	三维扫描仪（3DSS）：分辨率 ≤ 0.001 mm，测量精度 ≤ 0.035 mm	Three-dimensional scanner: resolution rate ≤ 0.001 mm, accuracy of measurement ≤ 0.035 mm
B96	85142000	工业或实验用感应或介质损耗工作的炉及烘箱：炉膛容量 > 100 t	Industrial or laboratory furnaces and ovens for work involving induction or dielectric loss: furnace capacity > 100 t
B97	84752919	行列式制瓶机：电子伺服驱动八组三滴料及其以上，电子伺服驱动十组双滴料及其以上，小口吹压（NNPB）设备	Individual section machines: electronic servo drive system (8 series -3 drip and above), electronic servo drive system (10 series -2 drip and above), NNPB (narrow neck press and blow) devices
B98	84741000	碎玻璃加工线或分选设备（有色金属分选机、碎玻璃去标签机、碎玻璃加工光学分选机）：处理能力 ≥ 12 t/h，剔除物/破碎玻璃处理量 ≥ 1%；处理后碎玻璃质量要求：磁性金属杂质 ≤ 0.1%，非磁性金属杂质 ≤ 2 颗/25 kg，石英、陶瓷、沙子等杂质 ≤ 1 颗/25 kg（杂质 Φ>2.5 mm）且 ≤ 4 颗/25 kg（杂质 Φ > 0.9 mm）	Cullet processing line and sorting devices (non-ferrous metal sorting machines, cullet tab removal machines, cullet processing optical sorting machines): processing ability ≥ 12 t/h, peeled-away processing capacity ≥ 1%; after treatment quality criteria of cullet: magnetic metal impurity ≤ 0.1%, non-magnetic metal impurity ≤ 2 pieces/25 kg, impurity such as quartz, ceramics, and grit ≤ 1 piece/25 kg (impurity Φ > 2.5 mm) and ≤ 4 pieces/25 kg (impurity Φ > 0.9mm)
B99	84752919	玻璃热加工设备：玻璃器皿压吹生产设备机速 ≥ 35 个/分钟，工位 > 16；高脚杯挺焊接拉伸机机速 ≥ 35 个/分钟，工位 > 48；激光爆口机机速 ≥ 35 个/分钟，工位 > 36	Glass-heating equipment: glass container pressing and blowing production equipment speed ≥ 35 pieces/min, stations > 16; goblet welding tensile machine speed ≥ 35 pieces/min, stations > 48; laser cracking-off machine speed ≥ 35 pieces/min, stations > 36
B100	84798990 84642010 84659300	数控自由曲面车房设备：内渐近镜片粗、精磨机	CNC free-form feature garage equipment: coarse and fine grinding machine with interior progressive lenses
B101	84862021	全自动镀膜设备：用于树脂镜片专用镀膜	Automatic coating equipment: used for resin lens coating
B102	90318090	高折射的镜片材料研发、检测设备：光谱分析设备、光谱反射检测设备	High-refraction lenses material research and testing equipment: spectrum analytical equipment, spectrum reflection detector
B103	85433000	阴阳极制造机（大型、自动化程度高、湿法冶金电积设备）	Cathode and anode manufacturing machines (large-scale, high degree of automation, hydrometallurgy electrowinning equipment)
B104	8477	直接法长纤维增强热塑性复合材料生产线	Direct long-fiber-reinforced thermoplastic composite material production line
B105		大型摩擦密封材料关键生产及测试设备	Large-scale friction sealing material key production and testing equipment
B106	84186990	连续冻干设备	Continuous freeze-drying equipment
B107	84798940	全自动包裹、文件分拣机：速度 ≥ 2.6 m/s	Package and document automatic sorting machines: speed ≥ 2.6 m/s
B108		荧光定量 PCR 仪，基因测序仪，流式细胞仪	Fluorescent quantitative polymerase chain reaction (PCR) gene sequencing machine and flow cytometer
B109	90221990	低能量 X 射线镀层测量仪，检测范围 0.5~16 mg/m^2	Low-energy X-ray coating measurer, detection range 0.5–16 mg/m^2

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B110		激光跟踪仪：最大允许示值误差 ± (15 μm + 被测长度 × 6 μm/m）	Laser tracker: maximum permissible indication error ± (15 μm + the measured length x 6 μm/m)
B111		激光干涉仪：最大允许线性示值误差 ± 0.5 ppm	Laser interferometer: maximum permissible linear indication error ± 0.5 ppm
B112		钢轨平直度检测设备：激光成像检测原理，检测速度 0~1.5 m/s，取样距离 ≤ 100 mm，测量精度 0.05 mm，数据处理时间要求钢轨通过后 3 秒内完成，测量范围 > 150 × 150 mm，无测量盲区	Steel rail flatness measuring equipment: laser imaging measurement principle, measuring speed: 0–1.5 m/s, sampling distance ≤ 100 mm, precision: 0.05 mm, data analyzing time: completed within 3 s after rail passed, measurement range > 150 × 150 mm, does not measure blind spots
B113		全自动布氏龙门硬度机。试验力误差: ± 0.5%；示值误差：1）HBW ≤ 125，误差 ≤ 2, 2) 125 < HBW ≤ 225，误差 ≤ 1.5 3）HBW > 225，误差 ≤ 1; 压痕测量装置示值误差: ± 0.0005 mm; 压痕直径分辨率: 0.0001 mm，硬度值读数分辨率: 0.01 HBW	Automatic Gantry Brinell hardness tester: measurement error: ± 0.5%; indication error: 1) HBW ≤ 125, error ≤ 2, 2) 125 < HBW ≤ 225, error ≤ 1.5, 3) HBW > 225, error ≤ 1; pressure trace measuring device indication error ± 0.0005 mm; diameter of pressing trace resolution ratio 0.0001 mm, hardness indicator resolution ratio 0.01 HBW
B114		磨削烧伤检测仪。主机分析频率: 70–200 kHz; 主机磁场频率: 1–500Hz	Grinding and burn inspector: analyzing frequency of main engine 70–200 kHz; magnetic field frequency of main engine 1–500 Hz
B115		棒材内部相控阵超声波探伤设备系统：0.8 mm，FBH，0.8 × 15，SDH	Inside bar phased array ultrasonic flaw inspection equipment system: 0.8 mm, FBH, 0.8 × 15, SDH
B116		棒材表面探伤漏磁检测设备系统：0.15 mm × 0.2 mm × 10 mm 表面槽	Bar surface flaw and magnetic leakage inspection equipment system: surficial groove 0.15 mm × 0.2 mm × 10 mm
B117		废晶体硅太阳能电池板资源回收成套装备：铝边框、玻璃破损率 ＜ 5%，有色金属回收率 ≥ 95%，贵金属回收率 ≥ 95%，硅料回收率 ≥ 90%	Crystalline silicon solar panel waste recycling set equipment: breakage rate of aluminum frame and glass < 5%, non-ferrous metal recycling rate ≥ 95%, precious metal recycling rate ≥ 95%, silicon recycling rate ≥ 90%
		船舶制造用关键件	Key parts and components used in ship manufacturing
B118	85015300	推进电动机	Propulsion motors
B119		双燃料柴油发电机组柴油机	Dual-fuel diesel generator sets and engines
B120	85372090	推进系统控制单元	Propulsion system control units
B121	85371090	锅炉燃烧器自动控制部分	Auto control sections of boiler burners
B122	85015200	变桨电机：AC 6–16 kW	Variable-pitch motor: AC 6–16 kW
B123	90141000	高精度姿态传感器：航向精度 ± 180° ± 0.1°，纵倾/横摇 ± 90° ± 0.1°，功耗不高于 15 W，最大工作深度不低于 1000 m	High-precision attitude sensor: heading precision ± 180° ± 0.1°, trim/rolling ± 90° ± 0.1°, no higher than 15 W power consumption, maximum operating water depth no lower than 1,000 m
		飞机制造用关键件(国内可生产的部件除外）	Key parts and components used in aircraft manufacturing (excluding components that can be produced domestically)
B124		发动机系统	Engine systems
B125		航电系统	Avionic systems
B126		主飞控系统	Primary flight control systems
B127		电源系统	Power supply systems

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B128		起落架系统	Landing gear systems
B129		燃油系统	Fuel systems
B130		辅助动力装置	Auxiliary power units
B131		液压系统	Hydraulic systems
		汽车整车和关键总成设计、试验装置	Automotive vehicle and key assembly design, test equipment
B132	90312000	汽车零部件性能试验装置（制动器系统试验台、转向器系统试验台、汽车热平衡系统匹配试验台、喷油系统综合性能试验台、汽车振动噪声测试平台、环境老化类试验设备、汽车零部件性能耐久试验台、轮胎/车轮用性能及耐久试验台、车身及附件耐久疲劳及性能测试系统、有害物质及有害气体采集及分析类设备、汽车灯具及电气用测试设备、商用车离合器综合性能试验台等）	Auto parts performance testing devices (braking system test bed, steering gear test bed, auto heat balance system match test bed, fuel injection system comprehensive performance test bed, auto vibration noise measurement bed, environment aging test equipment, auto parts performance endurance test, wheel performance and endurance test bed, bodywork and accessories endurance and fatigue test equipment system, hazardous substance and gas collection and analytical equipment, test equipment for auto lamps and electric systems, commercial vehicle clutch comprehensive performance test bed, etc.)
B133	902410	汽车金属材料性能试验装置（用于材料应力-应变测试、材料疲劳性能测试、材料高速应变测试等）	Auto metal material performance test equipment (used in material stress tests and strain tests, fatigue performance tests, strain tests at high speeds, etc.)
B134	90248000 90241010	汽车非金属材料性能试验装置（皮带性能试验台、燃油管、水管性能试验台等）	Auto non-metallic material performance test equipment (belt performance test platform, fuel pipes, pipe performance test platform, etc.)
B135	90312000	汽车动力总成试验装置（自动变速箱试验台、发动机测试试验台等）	Auto powertrain test equipment (automatic transmission test rig, engine tests, etc.)
B136	90312000	汽车底盘系统试验装置（悬挂测试系统试验台等）	Automotive chassis system test equipment (suspension test systems test bench, etc.)
B137	90312000	汽车整车试验台（整车匹配、性能、排放、耐久性能试验台；整车环境模拟试验装置；道路模拟试验台等）	Automotive vehicle test bed (vehicle matching, performance, emissions, durability test stands; vehicle environment simulation test devices; road simulation test bed, background air-handling test bed, etc.)
B138	90308990 90312000	汽车主被动安全试验装置（车碰撞牵引试验装置、台车模拟试验台、运动图像采集分析系统、行人保护试验台、车载数据采集系统、通用动态冲击试验台、光测量和声测量系统、高速采集用光照系统、动态发射式测试系统、激光测速装置、非接触测量系统、机械臂测试系统、高精度伺服发射测试系统、假人及假人模块冲击器（头部、胸部、腿部冲击器）、车身结构强度试验系统、光学测量和声学测量系统、高速采集用光照系统、动态发射式测试系统等）	Active and passive vehicle safety test devices (car crash traction test equipment, trolleys simulation test bed, moving image acquisition and analysis system, pedestrian protection test bed, in-car data acquisition system, general dynamic impact test bed, optical and acoustic measurement system, illumination system for use in high-speed acquisition, dynamic emission-type test system, laser velocimeter equipment, noncontact measurement system, manipulator test system, high-precision launching servo test system, dummy and dummy mold impactor (head, chest and leg impactor), strength test system for body structure, etc.)
B139		智能车控制技术测试：驾驶机器人（可模拟人踩油门、刹车以及转向等操作），假车（最高速度 > 60 km/h，最大加速度 > 0.5 g），假人（最高速度 > 20 km/h，最大加速度 > 0.1g），数采系统（频率 > 50Hz），定位系统（定位精度 < 5 cm）	Intelligent vehicle control technique test: robot driver (simulate human driver to step on accelerator and brake, steering, etc.), fake vehicle (maximum speed > 60 km/h, maximum acceleration > 0.5 g), dummy (maximum speed > 20 km/h, maximum acceleration > 0.1 g), data acquisition system (frequency > 50 Hz), positioning system (positioning accuracy < 5 cm)

Important Equipment Encouraged Imports 鼓励进口的重要装备 (continued)

No.	Product No.	Product (Chinese)	Product (English)
B140	90308990 90312000 90318090	汽车电子试验装置（EMC 测试系统、整车及发动机变速箱硬件在环仿真系统、VCT 标定试验台、GDI 泵嘴流量特性标定试验台等）	Auto electronics test equipment (EMC test systems, vehicle and engine transmission hardware-in-loop simulation systems, VCT calibration test stands, GDI pump nozzle flow characteristics calibration test bench, etc.)
B141	90312000	新能源汽车试验装置（电池试验台、电机测功机、EIPF&HIL 测试系统等）	New energy vehicle test equipment (battery test bench, motor dynamometric machine, EIPF&HIL testing systems, etc.)
B142	90271000 90318090	汽车尾气排放测试转鼓：THC/NO_x/CH_4 分析单元的最小量程 1 ppm，测试欧 5/6 和美国 LEVIII 及 TIER3 排放法规	Automobile exhaust emission test drum: THC/NO_x/CH_4 the smallest unit of analysis range 1 ppm, testing Europe 5/6 emission regulations, the US LEVIII and TIER3 emission regulations
B143	903040 903120 903180	NVH 分析和试验装置	NVH analysis and test equipment
		卫星制造用关键件（国内可生产的部件除外）	Satellite manufacturing key components (excluding components that can be produced domestically)
B144		控制与推进分系统	Control and propulsion subsystems
B145		测控分系统	Measurement and control subsystems
B146		电源分系统	Power supply subsystems
B147		数传分系统	Digital transmission subsystems
B148		导航分系统	Navigation subsystems
B149		转发器分系统	Repeater subsystems
B150		天线分系统	Antenna subsystems
B151		相机分系统	Camera subsystems

Key Industries Encouraged Imports 鼓励发展的重点行业

No.	Industry (Chinese)	Industry (English)
C1	太阳能热发电集热系统、太阳能光伏发电系统集成技术开发应用、逆变控制系统开发制造	Solar thermal power generation system, development and application of solar photovoltaic generation system integration technology and inverter control system
C2	海上风电机组技术开发与设备制造	Offshore wind turbine generator technology development and equipment manufacturing
C3	先进核反应堆建造与技术开发	Advanced nuclear reactor construction and equipment manufacturing
C4	核电站应急抢险技术开发与设备制造	Nuclear power station emergency and rescue technology development and equipment manufacturing
C5	高性能核燃料元件制造	Manufacturing components for high-performance nuclear fuel
C6	火力发电脱硝催化剂开发生产	Thermal power denitration catalyst development and production
C7	乏风瓦斯发电技术及开发利用	Development and utilization of ventilation air methane generation technology
C8	生物质直燃、气化发电技术开发与设备制造	Technology development and equipment manufacturing of biomass-fired and gasification power generation
C9	半导体照明设备，光伏太阳能设备，片式元器件设备，新型动力电池设备、表面贴装设备（含钢网印刷机、自动贴片机、无铅回流焊、光电自动检查仪）制造	Manufacturing of semiconductor lighting equipment, photovoltaic solar equipment, chip component equipment, new-type power battery equipment, surface mounting equipment (steel-net printer, automatic mounting machine, lead-free reflow soldering, photoelectric inspection tester, etc.)
C10	年产 800 万吨及以上煤矿洗选设备制造、年产 3,000 万吨及以上大型露天矿关键装备制造	Coal washing equipment manufacturing, capacity ≥ 8,000,000 tons/year; Large strip mine key equipment manufacturing, capacity ≥ 30,000,000 tons/year
C11	汽车产品开发、试验、检测设备及设施建设	Automobile product developing, testing, and detecting equipment and facilities construction
C12	新能源汽车关键零部件开发制造：能量型动力电池组（能量密度 ≥ 110 Wh/kg，循环寿命 ≥ 2,000 次），电池正极材料（比容量 ≥ 150 mAh/g，循环寿命 2,000 次不低于初始放电容量的 80％），电池隔膜（厚度 15~40 μm，孔隙率 40%~60%）；电池管理系统，电机管理系统，电动汽车电控集成；电动汽车驱动电机（峰值功率密度 ≥ 2.5 kW/kg，高效区：65%工作区效率≥80%），车用 DC/DC（输入电压 100 V~400 V），大功率电子器件（IGBT，电压等级 ≥ 600 V，电流 ≥ 300 A）；插电式混合动力机电耦合驱动系统	Development and manufacturing of new energy vehicle key components: energy power battery pack (energy density ≥ 110 Wh/kg, cycle life ≥ 2000 cycles), cathode material battery (specific capacity ≥ 150 mAh/g, cycle life 2,000 cycles, and no lower than 80% of initial discharge capacity), battery separator (thickness 15–40 μm, porosity 40–60%); battery management system, engine management, electromobile integrated electronic control; electromobile drive engine (peak power density ≥ 2.5 kw/kg, high efficiency area: 65% of workspace efficiency ≥ 80%), automobile used DC/DC (input voltage: 100–400 V), high-power electronic device (IGBT, voltage ≥ 600 V, current ≥ 300 A); plug-in hybrid electric vehicle coupling drive system
C13	动力定位系统、FPSO 单点系泊系统、大型海洋平台电站集成系统、主动力及传动系统（不含内燃动力）、钻井平台升降系统、采油系统等通用和专用海洋工程配套设备设计制造	General and special marine engineering support equipment design and manufacturing, such as dynamic positioning systems, FPSO single point mooring systems, large offshore power station integrated systems, active force and transmission systems (excluding internal engine), drilling platform lifting systems, oil production systems, etc.
C14	12,000 米及以上深井钻机、极地钻机、高位移性深井沙漠钻机、沼泽难进入区域用钻机、海洋钻机、车装钻机、特种钻井工艺用钻机等钻机成套设备制造	Drilling set equipment manufacturing, such as ≥ 12,000 m deep drilling rig, polar drilling rig, high displacement deep drilling desert rig, drilling rigs used in hard-to-access areas (such as bogs), marine drilling rig, automobile drilling rig, special drilling manufacturing technology, etc.

Key Industries Encouraged Imports 鼓励发展的重点行业 (continued)

No.	Industry (Chinese)	Industry (English)
C15	智能焊接设备，激光焊接和切割、电子束焊接等高能束流焊割设备，搅拌摩擦、复合热源等焊接设备，数字化、大容量逆变焊接电源制造	High-octane beam welding and cutting equipment, such as intelligent welding equipment, laser welding and laser cutting, electron beam welding, friction stir welding and hybrid welding, power source manufacturing for digital and large-capacity inverter welding
C16	7,200 千瓦及以上交流传动电力机车、6,000 马力及以上交流传动内燃机车、时速 200 公里以上动车组、海拔 3,000 米以上高原机车、大型专用货车、机车车辆特种救援设备制造及技术开发	Equipment manufacturing and development technology for 7,200 kW and above alternating current drive electric locomotives, 6,000 horse power and above AC internal engine vehicles, 200 km/h and above railway multiple units, 3,000 meters above sea level high-land locomotives, large-size special trucks and special rescue vehicles
C17	干线轨道车辆交流牵引传动系统、制动系统及核心元器件（含 IGCT、IGBT 元器件）制造	Track vehicle alternating current traction drive system, brake system and core components manufacturing (including IGCT, IGBT core components)
C18	四轴以上联动的高速、精密数控机床及配套数控系统、伺服电机及驱动装置、功能部件、刀具、量具、量仪及高档磨具磨料制造	Four-axis and higher linkage high-speed and precision CNC machine tool and supporting CNC systems, servomotor and drive devices, functional units, cutters, measuring instrument and high-end grinding tool and abrasive manufacturing
C19	耐高低温、耐腐蚀、耐磨损精密铸锻件制造	High and low temperature-resistant, corrosion-resistant, and abrasion-resistant precise casting and forging manufacturing
C20	147 kW 以上大型拖拉机及关键零部件的开发与制造	Development and manufacturing of 147 kW and above large tractors and key components
C21	147 kW 以上大型拖拉机配套农机具开发与制造	Development and manufacturing of 147 kW and above large tractors and supporting agricultural equipment
C22	甘蔗收获机（自走式或拖拉机背负式，配套功率 > 58 kW，宿根破碎率 ≤ 18%，损失率 ≤ 7%）制造	Sugarcane harvester manufacturing (self-propelled or back-pack tractor, supporting power > 58 kW, damage rate of perennial roots ≤ 18%, loss ratio ≤ 7%)
C23	自走式谷物联合收割机（喂入量 10 kg/s 以上）制造	Self-propelled grain combined harvester manufacturing (feed quantity 10 kg/s and above)
C24	农作物移栽机械制造：乘坐式盘土机动高速水稻插秧机为每分钟插次 350 次以上，每穴 3~5 株，适应行距 20~30 厘米，株距可调，适应株距 12~22 厘米；盘土式机动水稻摆秧机为乘坐式或手扶式，适应行距为 20~30 厘米，株距可调，适应株距为 12~22 厘米	Crop transplanter manufacturing: sitting-type planosol soil motorized high-speed rice transplanter (350 times/minute and above, 3–5 per pit, line spacing 20–30 cm, adjustable row spacing 12–22 cm); sitting or walking-type planosol rice seedling arranging machine (line spacing 20–30 cm, adjustable row spacing 12–22 cm)
C25	牧草收获机械制造：自走式牧草收割机、指盘式牧草搂草机、牧草捡拾压捆机等	Herbage reaper manufacturing: self-propelled herbage reapers, indicator herbage reapers, herbage baling machines, etc.
C26	节水灌溉设备制造：各种大中型喷灌机、各种类型微滴灌设备；抗洪排涝设备：排水量 1,500 m^3/h 以上，扬程 5~20 m，功率 1,500 kW 以上，效率 60%以上，可移动	Water-saving irrigation equipment manufacturing: all kinds of large and medium sprinkling machine and micro-trickle irrigation equipment; anti-flood drainage equipment (drainage rate 1,500 m^3/h and above, lift 5–20 m, power 1,500 kW and above, efficiency 60% and above, mobile)
C27	TFT-LCD、OLED、激光显示、3D 显示、柔性显示等新型平板显示器件生产专用设备设计制造	Design and manufacturing of special equipment for new-style flat-panel display production, such as TFT-LCD, PDP, OLED panels, laser displays, 3D displays, and flexible displays
C28	新型电子元器件（片式元器件、频率元器件、混合集成电路、电力电子器件、光电子器件、敏感元器件及传感器、新型机电元件、高密度印刷电路板和柔性电路板等）制造	New-style electron component manufacturing (chip components, frequency components, mixed integrated components, power electronic components)

Key Industries Encouraged Imports 鼓励发展的重点行业 (continued)

No.	Industry (Chinese)	Industry (English)
C29	大中型电子计算机、万万亿次高性能计算机、便携式微型计算机、每秒一万亿次及以上高档服务器、大型模拟仿真系统、大型工业控制机及控制器制造	Large and medium electronic computers, 10 petaflop high-performance computers, portable microcomputers, teraflop high-end servers, large-size analog simulation systems, large-size industrial computer and controller manufacturing
C30	集成电路设计，线宽 0.8 μm 以下集成电路制造，及球栅阵列封装（BGA）、插针网格阵列封装（PGA）、芯片规模封装（CSP）、多芯片封装（MCM）等先进封装与测试；集成电路装备制造	Advanced packaging and testing: integrated circuit design, IC manufacturing (line width ≤ 0.8 μm), ball grid array (BGA), ceramic pin grid array package (PGA), chip scale packaging (CSP), multi-chip package (MCM), etc.; integrated circuit equipment manufacturing
C31	半导体、光电子器件、新型电子元器件等电子产品用材料制造	Electronic products, such as semiconductors, optoelectronic devices, and new-type electronic components, using material manufacturing
C32	先进的各类太阳能光伏电池及高纯晶体硅材料（单晶硅光伏电池的转化效率 > 20%，多晶硅电池的转化效率 > 18%，硅基薄膜电池转化效率 > 12%，碲化镉电池的转化效率 > 13%，铜铟镓硒电池转化效率 > 12%）制造	All types of advanced solar photovoltaic battery and high-purity silicon crystals material manufacturing (conversion efficiency of monocrystalline silicon battery > 20%, conversion efficiency of polycrystalline silicon > 18%, conversion efficiency of Si-based thin film battery > 12%, conversion efficiency of cadmium telluride battery > 13%, conversion efficiency of copper-indium-gallium-diselenide battery > 12%)
C33	聚丙烯热塑性弹性体(PTPE)、热塑性聚酯弹性体(TPEE)、苯乙烯-异戊二烯-苯乙烯热塑性嵌段共聚物（SIS）、热塑性聚氨酯弹性体等热塑性弹性体材料开发与生产	Thermoplastic elastomer material development and production, such as polypropylene thermoplastic elastomer (PTPE), thermo-plastic elastomer polyester (TPEE), styrene-isoprene-styrene (SIS), and thermoplastic polyurethane elastomer
C34	卫星通信系统、地球站设备制造	Manufacturing of satellite communication systems and earth sta-tion equipment
C35	数据通信网设备制造	Data communication network equipment manufacturing
C36	宽带网络设备制造	Broadband network equipment manufacturing
C37	航空发动机开发制造	Aero-engine development and manufacturing
C38	医疗电子、金融电子、航空航天仪器仪表电子、传感器电子等产品制造	Medical electronics, financial electronics, aerospace instruments and meters, sensor electronics manufacturing
C39	干线、支线、通用飞机及零部件开发制造	Main line, branch line, general airplane and components develop-ment and manufacturing
C40	先进适用的建筑成套技术、产品和住宅部品研发与推广	Advanced and practicable architecture set technology and prod-ucts and residential products research, development, and market promotion
C41	危险废弃物（放射性废物、核设施退役工程、医疗废物、含重金属废弃物）安全处置技术设备开发制造及处置中心建设	Safe waste disposal technical equipment development and manu-facturing and disposal center construction for hazardous waste (radioactive waste, nuclear installation decommissioning projects, medical waste, waste containing heavy metal)
C42	高效、低能耗污水处理与再生技术开发	High-efficiency, low-energy sewage treatment and renewable technology development
C43	优质钾肥及各种专用肥、缓控释肥的生产，氮肥企业节能减排和原料结构调整，磷石膏综合利用技术开发与应用，年产 10 万吨及以上湿法磷酸净化生产装置	High-grade potash fertilizer and all kinds of special fertilizers, slow controlled-release fertilizer production, energy saving and emis-sion reduction and raw material structure adjustment for nitroge-nous fertilizer enterprises, phosphogypsum comprehensive utiliza-tion technology development and application, wet-process phosphoric acid purification production equipment with capacity of 100,000 tons/year or more
C44	核设施退役及放射性废物治理	Nuclear installation decommissioning and radioactive waste treatment

Key Industries Encouraged Imports 鼓励发展的重点行业 (continued)

No.	Industry (Chinese)	Industry (English)
C45	大气污染治理装备：300 兆瓦以上燃煤电站烟气 SCR 脱硝技术装备（脱氮效率 90%以上，催化剂使用寿命 16000 小时以上）；钢铁烧结烟气循环流化床干法脱硫除尘成套装备（钙硫比：1.2~1.3）；1000 兆瓦超超临界机组配套电除尘技术装备；电袋复合除尘技术装备（烟尘排放浓度<30 毫克/立方米）；1000 兆瓦超超临界以上机组脱硫氧化多级离心鼓风机（风量≥450 立方米/分钟、升压≥14000 毫米水柱）；等离子体废气净化机（废气去除率>95%）	Air pollution treatment equipment: 300 megawatt and above coal-fired power plants: SCR flue gas denitration technical equipment (denitration efficiency > 90%, service life of catalyzer 16,000 hours and above); steel sintering circulating fluidized bed dry flue gas desulfurization and precipitation technical equipment (calcium sulfur ratio 1.2–1.3); 1,000 mW ultra-supercritical unit supporting electrical dust precipitation technical equipment; electro-bag composite precipitation technical equipment (dust emission concentration < 30 mg/m³); 1,000 mW ultra-supercritical unit desulfuration oxidation multi-stage centrifugal blowers (airflow rate ≥ 450 m³/min, boost ≥ 14,000 mm water column); plasma exhaust purification machine (exhaust removal rate > 95%)
C46	“三废”综合利用及治理工程	“Three waste” comprehensive utilization and treatment projects
C47	节能、节水、节材环保及资源综合利用等技术开发、应用及设备制造	Development, application of technology, and manufacturing of equipment for use in energy, water and material saving, environmental protection, and resource comprehensive utilization
C48	废旧电器电子产品、废印刷电路板、废旧电池、废旧船舶、废旧农机、废塑料、废橡胶、废弃油脂等再生资源循环利用技术与设备开发	Renewable resource recycling technology and equipment development for waste electrical and electronic products, waste printed circuit board, waste battery, waste watercraft, waste agriculture machinery, waste plastic, waste rubber, waste oil, etc.
C49	废旧汽车、工程机械、矿山机械、机床产品、农业机械、船舶等废旧机电产品及零部件再利用、再制造，墨盒、有机光导鼓的再制造（再填充）	Recycling and remanufacturing of waste mechanical and electrical products and accessories such as waste automotive, engineering machinery, mine machinery, machine tool products, agricultural machinery, watercraft, etc.; cartridge and organic photoconductive drum remanufacturing (refilling)
C50	高效、节能、低污染、规模化再生资源回收与综合利用: 1) 废杂有色金属回收, 2) 有价元素的综合利用, 3) 赤泥及其它冶炼废渣综合利用, 4) 高铝粉煤灰提取氧化铝	High-efficiency, energy-saving, low-pollution, scale renewable resource recycling and comprehensive utilization: 1) recycling of waste non-ferrous metals; 2) valuable elements comprehensive utilization; (3) comprehensive utilization of red mud and other smelting waste; 4) extraction of alumina from high-alumina fly ash
C51	煤调湿、风选调湿、捣固炼焦、配型煤炼焦、干法熄焦、导热油换热、焦化废水深度处理回用、煤焦油精深加工、苯加氢精制、煤沥青制针状焦、焦油加氢处理、焦炉煤气高附加值利用等先进技术的研发与应用	R&D and application of advanced technologies, such as coal moisture control, wind moisture control, tampering coking process, formed-coal coking, coke dry quenching, heat transfer fluid transmission, coking waste deep treatment recycling, coal tar finishing, benzene hydro refining process, production of needle coke from coal pitch, coal tar hydrogenation, coke oven gas high value-added utilization, etc.
C52	利用工业副产石膏生产新型墙体材料及技术装备开发与制造	New-style wall materials and technical equipment development and manufacturing using industrial by-product gypsum
C53	污水防治技术设备制造：中小城镇一体化污水处理成套技术装备，超生耦合法和生物膜法处理高浓度有机废水技术装备	Sewage treatment technical equipment manufacturing: all-in-one sewage treatment equipment sets for medium- and small-sized towns, high-concentration organic wastewater process technical equipment using ultrasonic coupling and biomembrane methods
C54	固体废物防治技术设备制造：油田钻井废弃物处理处置技术与成套装备（减容 > 50%，处理率 > 70％）	Solid waste prevention and treatment technical equipment manufacturing: oil field well drilling waste disposal and treatment technology and equipment (volume reduction > 50%, disposal rate > 70%)
C55	城镇垃圾及其他固体废弃物减量化、资源化、无害化处理和综合利用工程	Urban waste and other solid waste reduction, reuse, hazard-free treatment, and comprehensive utilization projects
C56	餐厨废弃物资源化利用技术开发及设施建设	Kitchen waste transfer to resources utilization technology development and equipment establishment

Key Industries Encouraged Imports 鼓励发展的重点行业 (continued)

No.	Industry (Chinese)	Industry (English)
C57	含持久性有机污染物土壤修复技术的研发与应用	R&D and application of restoration technology of soil containing persistent organic pollutants
C58	微咸水、苦咸水、劣质水、海水的开发利用及海水淡化工程	Brackish water, bitter water, marginal water, seawater development and utilization and seawater desalination projects
C59	碳捕获、存储及利用技术装备制造	Carbon capture, storage, and utilization equipment manufacturing
C60	废旧纺织品回收再利用技术与产品生产，聚酯回收材料生产涤纶工业丝、差别化和功能性涤纶长丝等高附加价值产品	Waste textiles recycling technology and production; high value-added products from recycled polyester materials such as polyester industrial filament, functional polyester filament yarn, etc.
C61	数字多功能一体化办公设备（复印、打印、传真、扫描）、数字照相机、数字电影放映机等现代文化办公设备制造	Modern office equipment manufacturing, such as digital multi-functional office equipment (copy, print, fax, scan), digital cameras, digital movie projectors, etc.
C62	物联网（传感网)、智能网等新业务网设备制造与建设	New service network equipment manufacturing and establishment, such as IoT (sensor networks) and intelligent networks
C63	数字化技术、高拟真技术、高速计算技术等新兴文化科技支撑技术建设及服务	Emerging culture and science to support technology building and service, such as digital technology, simulation technology, high-speed calculation technology, etc.
C64	现代生物技术药物、重大传染病防治疫苗和药物、新型诊断试剂的开发和生产，大规模细胞培养和纯化技术、大规模药用多肽和核酸合成、发酵、纯化技术开发和应用，采用现代生物技术改造传统生产工艺	Modern biotechnology pharmaceuticals, severe infectious disease, vaccine-preventable disease control, development and production of medicine and new-type diagnostic reagents, large-scale cell culture and purification technologies, large-scale officinal polypeptide and nucleic acid synthesis, fermentation, purification technology development and application, using modern biotechnology to transform traditional production technology
C65	新型医用诊断医疗仪器设备、微创外科和介入治疗装备及器械、医疗急救及移动式医疗装备、康复工程技术装置、家用医疗器械、新型计划生育器具（第三代宫内节育器）、新型医用材料、人工器官及关键元器件的开发和生产，数字化医学影像产品及医疗信息技术的开发与应用	New style medical diagnostic equipment, minimally invasive surgery and interventional therapy equipment, medical first aid and mobile medical equipment, rehabilitation technical devices, household medical machinery, new-style family planning tools (third-generation intrauterine devices), development and production of new-style medical material, artificial organs and key components, development and application of digital medical imaging products and medical information technology
C66	高性能、高质量及升级换代钢材产品技术开发与应用。包括 600 兆帕级及以上高强度汽车板、油气输送高性能管线钢、高强度船舶用宽厚板、海洋工程用钢、420 兆帕级及以上建筑和桥梁等结构用中厚板、高速重载铁路用钢、低铁损高磁感硅钢、耐腐蚀耐磨损钢材、节约合金资源不锈钢（现代铁素体不锈钢、双相不锈钢、含氮不锈钢）、高性能基础件（高性能齿轮、12.9 级及以上螺栓、高强度弹簧、长寿命轴承等）用特殊钢棒线材、高品质特钢锻轧材（工模具钢、不锈钢、机械用钢等）等	High-performance, high-quality, and new-style steel products technical development and applications such as 600 MPa and above high-strength sheet metal for autos, oil and gas transmission high-performance pipeline steel, wide heavy plate for high-strength watercraft, steel for use in marine engineering, 420 MPa and above heavy plate for building and bridge structure used, high-speed heavy-load steel for railways, low iron loss and high induction silicon steel, anti-corrosive and anti-abrasive steel, stainless steel using less alloy (modern ferrite stainless steel, duplex stainless steel, nitrogen-containing stainless steel), high-performance basic mechanical parts (high-performance gear, 12.9 grades and above bolts, high-strength springs, long service life bearings, etc.) special steel rods and wire stock, high-quality rolled steel (tool and mold steel, stainless steel, machinery), etc.

Key Industries Encouraged Imports 鼓励发展的重点行业 (continued)

No.	Industry (Chinese)	Industry (English)
C67	信息、新能源有色金属新材料生产: 1）信息：直径 200 mm 以上的硅单晶及抛光片、直径 125 mm 以上直拉或直径 50 mm 以上水平生长化合物半导体材料、铝铜硅钨钼等大规格高纯靶材、超大规模集成电路铜镍硅和铜铬锆引线框架材料、电子焊料等; 2）新能源：核级海绵锆及锆材、高容量长寿命二次电池电极材料	Production of Information and new energy new non-ferrous metal materials for use in information and new energy industry material production: 1) Information: diameter > 200 mm silicon monocrystal and polished sections, diameter > 125 mm and diameter > 50mm horizontal growth compound semiconductor material, large-scale and high-purity aluminum copper silicon tungsten and molybdenum target, super-large-scale integrated circuit copper-nickel-silicon and copper-chromium-zirconium lead frame, electronic solder, etc.; 2) New energy: nuclear grade zirconium sponge and zirconium material, high-storage-capacity and long-service-life battery electrode material
C68	交通运输、高端制造及其他领域有色金属新材料生产: 1）交通运输：抗压强度不低于 500 MPa、导电率不低于 80% IACS 的铜合金精密带材和超长线材制品等高强高导铜合金、交通运输工具主承力结构用的新型高强、高韧、耐蚀铝合金材料及大尺寸制品（航空用铝合金抗压强度不低于 650 MPa，高速列车用铝合金抗压强度不低于 500 MPa); 2）高端制造及其他领域：高性能纳米硬质合金刀具和大晶粒硬质合金盾构刀具及深加工产品、稀土及贵金属催化剂材料、低模量钛合金材及记忆合金等生物医用材料、耐蚀热交换器用铜合金及钛合金材料、高性能稀土磁性材料和储氢材料及高端应用	Non-ferrous metal new material production for transportation, high-end manufacturing, and other fields: 1) Transportation: high-strength and high-conductivity copper alloy, primary structures of transportation using new-style, high-strength, high-toughness, corrosion resistant all-alloy material and large-size products (aluminum alloy for use in aerospace: compressive strength ≥ 650 MPa; aluminum alloy for use in high-speed trains: compressive strength ≥ 500 MPa) such as IACS copper alloy precise strip (compressive strength ≥ 500 MPa, conductivity ≥ 80%), super long wire stock products; 2) High-end manufacturing and other fields: high-performance nano-grained cemented carbide cutter and large grain cemented carbide shield cutter and deep processing product, catalyzer material of rare earth and precious metal, biomedical material such as low-modulus titanium alloy material and memory alloy, corrosion resistant heat exchanger used copper alloy and titanium alloy material, high-performance rare earth magnetic material, hydrogen storage material and high-end application
C69	高新技术领域需求的高纯、超细、改性等精细加工的高岭土、石墨、硅藻土等非金属矿深加工材料生产及其技术装备开发与制造	High-technology sectors using high-purity, superfine, and modified non-metal mine deep processing material (kaolin, graphite, diatomite, etc.) production and technical equipment development and manufacturing
C70	航天航空等领域所需的特种玻璃制造技术开发与生产	Aerospace and aviation using special glass manufacturing technology development and production
C71	航空航天用新型材料开发生产	Aerospace and aviation using new-style material development and production
C72	年产 5 万吨及以上无碱玻璃纤维池窑拉丝技术和高性能玻璃纤维及制品技术开发与生产	Alkali-free glass fiber pool kiln wiredrawing technology with capacity of 50,000 tons/year and above and high-performance glass fiber and products technology development and production
C73	锂二硫化铁、锂亚硫酰氯等新型锂原电池；锂离子电池、氢镍电池、新型结构（卷绕式、管式等）密封铅蓄电池等动力电池；储能用锂离子电池和新型大容量密封铅蓄电池；全钒液流电池；超级电池和超级电容器制造	New-style lithium batteries, such as lithium iron disulfide batteries, lithium-thionyl chloride batteries; lithium-ion batteries, nickel-hydrogen batteries, new structure (coiled and tubular type) sealed lead-acid batteries; lithium batteries and new large-size sealed lead-acid batteries; all vanadium flow batteries; super batteries and supercapacitor manufacturing
C74	国家级工程（技术）研究中心、国家工程实验室、国家认定的企业技术中心、重点实验室、高新技术创业服务中心、新产品开发设计中心、科研中试基地、实验基地建设	Construction of state-level project (technology) research centers, national engineering laboratories, state-certified enterprise technology centers, key laboratory of high-tech innovation service centers, new product development design centers, research and pilot bases, experimental bases

Key Industries Encouraged Imports 鼓励发展的重点行业 (continued)

No.	Industry (Chinese)	Industry (English)
C75	有机和无机高性能纤维及制品的开发与生产（碳纤维（CF）（拉伸强度 ≥ 4,200 MPa，弹性模量 ≥ 240 GPa）、芳纶（AF）、芳砜纶（PSA）、高强高模聚乙烯（超高分子量聚乙烯）纤维（UHMWPE）（纺丝生产装置单线能力≥300 吨/年）、聚苯硫醚纤维（PPS）、聚酰亚胺纤维（PI）、聚四氟乙烯纤维（PTFE）、聚苯并双噁唑纤维（PBO）、聚芳噁二唑纤维（POD）、玄武岩纤维（BF）、碳化硅纤维（SiCF）、高强型玻璃纤维（HT-AR）等）	Development and production of organic and inorganic high-performance fiber and products, such as carbon fiber (tensile strength ≥ 4,200 MPa, modulus of elasticity ≥ 240 GPa), aramid fiber, polysulfonamide (PSA), high-strength and high-modulus polyethylene fiber (ultra-high molecular weight polyethylene, UHMWPE), spinning output ≥ 300 tons/year, polyphenylene sulfide fiber (PPS), polyimide fiber (PI), polytetrafluoroethylene fiber (PTFE), poly (p-phenylene-2,6-benzobisoxazole) fiber (PBO), poly (p-phenylene-1,3,4-oxadiazoles) fiber (POD), basalt fiber (BF), silicon carbide fiber (SiCF), high-strength fiberglass (HT-AR), etc.
C76	制革及毛皮加工清洁生产、皮革后整饰新技术开发及关键设备制造、皮革废弃物综合利用	Cleaner production of tanning and fur manufacturing, new leather finishing technology development and key equipment manufacturing, leather waste comprehensive utilization
C77	生物可降解塑料及其系列产品开发、生产与应用	Biodegradable plastic and series products development, production, and application
C78	高效太阳能热水器及热水工程，太阳能中高温利用技术开发与设备制造	High-efficiency solar water heater and water heating projects, solar energy medium- and high-temperature utilization technology development and equipment manufacturing
C79	牛羊胚胎（体内）及精液工厂化生产	Cattle and sheep embryos (in vivo) and semen factory production projects

Resource Products and Raw Materials 资源性产品、原材料

No.	Product No.	Product (Chinese)	Product (English)
D1	26040000	镍矿砂及其精矿：镍含量 ≥ 7.5%	Nickel ore and concentrate: nickel content ≥ 7.5%
D2	26100000	铬矿砂及其精矿：三氧化二铬含 ≥ 42%	Chromium ore and concentrate: chromium oxide content ≥ 42%
D3	26140000	钛矿砂及其精矿：二氧化钛含量 ≥ 48%	Titanium ore and concentrate: titanium dioxide content ≥ 48%
D4	26020000	锰矿砂及其精矿：锰含量 ≥ 36%	Manganese ore and concentrate: manganese content ≥ 7.5%
D5	26151000	锆矿砂及其精矿：锆含量 ≥ 65%	Zirconium ore and concentrate: zirconium content ≥ 65%
D6	26090000	锡矿砂及其精矿：锡含量 ≥ 60%	Tin ore and concentrate: tin content ≥ 60%
D7	26159010 26159090	铌矿砂及其精矿	Niobium ore and concentrate
D8	26159010 26159090	钽矿砂及其精矿	Tantalum ore and concentrate
D9		钨矿砂及其精矿， WO_3 含量 ≥ 45%	Tungsten ore and concentrate, content of WO_3 ≥ 45%
D10	26030000	铜精矿：铜含量 ≥ 25%	Copper concentrate: copper content ≥ 25%
D11	26070000	铅精矿：铅含量 ≥ 60%	Lead concentrate: lead content ≥ 60%
D12	26080000	锌精矿：锌含量 ≥ 45%	Zinc concentrate: zinc content ≥ 45%
D13	26050000	钴精矿：钴含量 ≥ 6%	Cobalt concentrate: cobalt content ≥ 6%
D14	26131000	钼精矿：钼含量 ≥ 51％	Molybdenum concentrate: molybdenum content ≥ 51%

D15	261710	锑精矿：锑含量 ≥ 30％	Antimony concentrate: antimony content ≥ 30%
D16	71104100	铱粉：铱含量 ≥ 99.95%， 粒度细于 200 目	Iridium powder: iridium content ≥ 99.95%, granularity finer than 200 mesh
D17	72026000	镍铁	Nickel-iron
D18	28441000	天然铀	Natural uranium
D19	72024100	铬铁	Chromium iron

Source: Ministry of Commerce, "鼓励进口技术和产品目录 (2015 年版)" [2015 Catalogue of Encouraged Technologies and Products for Imports], August 7, 2015, http://www.mofcom.gov.cn/article/difang/201508/20150801074747.shtml.

Appendix C: Notes for Table 17, US Net Imports from China: Sensitivity Analysis

Table 17 contains estimates of the plausible range of changes in US Net Imports (Exports – Imports) within eight specific high-technology sectors. The assumptions on which those estimates are based are described here. In this Appendix, "now" and "currently" refer to 2015 data from the US Customs Service.

1. **5G telecommunications equipment.** US net imports of telecommunications equipment from China are currently $61.8 billion.
   - The low estimate assumes this figure is reduced 10 and 20 percent respectively in 2017 and 2020 due to falling unit costs and slower growth.
   - The high estimate assumes increases of 10 and 20 percent respectively, reflecting plausible capture of component production by Chinese firms.
2. **Integrated circuits (integrated circuits and IC machinery).** The United States currently has a $3 billion export surplus of ICs and a $1.4 billion exports surplus of IC fabrication equipment.
   - The low estimate is for a 10 percent increase in gross US IC ex-ports to China in 2017, dropping to zero in 2020, and a 25 percent increase in fabrication equipment exports in 2017, increasing to 50 percent in 2020.
   - The high estimate is zero increase in US exports in 2017, and a doubling of imports in 2020 plus a 10 percent reduction in US exports, for ICs, and a 40 percent reduction in US exports of IC machinery to China in 2020.
3. **Additive manufacturing.** Additive manufacturing low estimate assumes no change in Chinese penetration of US market, plus US exports 10 percent share of Chinese market of $2 billion. High estimate assumes a doubling of the US market by 2020 and a Chinese penetration rate of 40 percent.
4. **Robotics. T**he Chinese robotics market is currently about $1.2 billion.
   - The low estimate assumes 30 percent growth and US penetration of 10 percent, with no US imports from China.
   - The high estimate assumes no increase in US exports and Chinese imports increasing to 5 percent of the US market.
5. **Electric vehicles.** Electric vehicles based on unit estimates: The United States could export a maximum of 1,000 units to China in 2017 and 10,000 in 2020, with a unit value of $100,000. China could export a maximum of 10,000 units to the United States in 2017 and 100,000 in 2020, with a unit value of $50,000.
6. **High speed rail.** High estimate based on construction of one HSR line in the United States by 2020, supplied with Chinese rolling stock. Low estimate based on no US HSR construction and no US sales of equipment to China.
7. **Biopharmaceuticals.** In the low estimate, the Chinese biopharmaceuticals market is assumed to total $90 billion in 2017 and $150 billion in 2020, with US export penetration reaching 10 percent. In the high estimate, the US biopharmaceuticals market reaches $150 billion in 2017 and $175 billion in 2020, with Chinese import penetration reaching 5 percent in 2017 and 10 percent in 2020.
8. **Medical instruments.** In the low estimate on medical instruments, current US export surplus of 0.55 (HS 9018 only), expands by 5 percent of overall Chinese medical instrument market estimated at $54 billion in 2017 and 7 percent of $75 billion in 2020. In the high estimate, Chinese imports expand to 10 percent of US market estimated at $120 billion in 2020.