SECTION 2: EMERGING TECHNOLOGIES AND MILITARY-CIVIL FUSION: ARTIFICIAL INTELLIGENCE, NEW MATERIALS, AND NEW ENERGY

Key Findings

- China's government has implemented a whole-of-society strategy to attain leadership in artificial intelligence (AI), new and advanced materials, and new energy technologies (e.g., energy storage and nuclear power). It is prioritizing these areas because they underpin advances in many other technologies and could lead to substantial scientific breakthroughs, economic disruption, enduring economic benefits, and rapid changes in military capabilities and tactics.
- The Chinese government's military-civil fusion policy aims to spur innovation and economic growth through an array of policies and other government-supported mechanisms, including venture capital (VC) funds, while leveraging the fruits of civilian innovation for China's defense sector. The breadth and opacity of military-civil fusion increase the chances civilian academic collaboration and business partnerships between the United States and China could aid China's military development.
- China's robust manufacturing base and government support for translating research breakthroughs into applications allow it to commercialize new technologies more quickly than the United States and at a fraction of the cost. These advantages may enable China to outpace the United States in commercializing discoveries initially made in U.S. labs and funded by U.S. institutions for both mass market and military use.
- *Artificial intelligence:* Chinese firms and research institutes are advancing uses of AI that could undermine U.S. economic leadership and provide an asymmetrical advantage in warfare. Chinese military strategists see AI as a breakout technology that could enable China to rapidly modernize its military, surpassing overall U.S. capabilities and developing tactics that specifically target U.S. vulnerabilities.
- *New materials:* Chinese firms and universities are investing heavily in building up basic research capabilities and manufacturing capacity in new and advanced materials, including through acquisition of overseas firms, talent, and intellectual property. These efforts aim to close the technological gap with the United States and localize production of dual-use materials integral to high-value industries like aerospace. They could also enable China to surpass the United States in applying breakthrough discoveries to military hardware.

- *Energy storage:* China has quickly built up advanced production capacity in lithium-ion batteries and established control over a substantial portion of the global supply chain, exposing the United States to potential shortages in critical materials, battery components, and batteries. China's heavily subsidized expansion in lithium-ion batteries will likely lead to excess capacity and drive down global prices. If Chinese producers flood global markets with cheaper, technologically inferior batteries, it would jeopardize the economic viability of more innovative energy storage technologies currently under development in the United States.
- *Nuclear power:* China is positioning itself to become a leader in nuclear power through cultivating future nuclear export markets along the Belt and Road, particularly in sub-Saharan Africa, and attracting advanced nuclear reactor designers to build prototypes in China.

Recommendations

The Commission recommends:

- Congress direct the U.S. Department of Justice to reestablish a higher education advisory board under the Federal Bureau of Investigation. In concert with the U.S. Department of Commerce's Bureau of Industry and Security, U.S. Department of Homeland Security, and U.S. Department of State, the higher education advisory board would convene semiannual meetings between university representatives and relevant federal agencies to review the adequacy of protections for sensitive technologies and research, identify patterns and early warning signs in academic espionage, assess training needs for university faculty and staff to comply with export controls and prevent unauthorized transfer of information, and share other areas of concern in protecting national security interests related to academic research.
- Congress direct the U.S. Government Accountability Office to conduct an assessment on the risks posed by Beijing's efforts to co-opt foreign researchers or students at U.S. universities to unlawfully appropriate research and other knowledge for the benefit of the government, companies, or interests of the People's Republic of China. This report should:
  - Include the number of foreign students and researchers from China studying in science, technology, engineering, and mathematics fields; past and current affiliations; primary areas of research; duration of stay in the United States; and subsequent employment;
  - Identify whether federally funded university research related to emerging technologies may have been unlawfully appropriated by individuals acting on behalf of Chinese entities; and
  - Evaluate the efficacy and ability of the U.S. Department of State's visa screening mechanism to mitigate the risk of inappropriate technology transfer to China, including but not limited to: assessing the ability of that process to identify students, researchers, and research entities, through a visa disclosure requirement, that are receiving funding from the

government of China or an intermediary entity acting in support of China's government.

- Congress amend Internal Revenue Code Section 41 to extend the research and development tax credit to initial stages of deployment for new products, processes, computer software, techniques, formulae, or inventions that increase the production of final and intermediary goods manufactured primarily in the United States. The tax credit should also extend to precompetitive commercial development of basic and applied research performed in the United States, particularly in industrial sectors where the People's Republic of China threatens the technological leadership of the United States.
- Congress direct the U.S. Geological Survey, in coordination with the U.S. Department of Energy, U.S. Department of Commerce, U.S. Department of the Interior and U.S. International Trade Commission to develop and maintain a risk assessment framework that identifies materials used in manufacturing industries critical to both national security and commercial vitality. Such a framework should provide an early warning mechanism for any threats to the U.S. supply of these critical materials, including an increasing concentration of extraction and processing by another country or entity and acquisition of significant mining and processing facilities; increasing export restrictions by another country; large gaps between domestic prices for these materials in another country versus prices on international markets; sharp increases or volatility in price; and substantial control in supply of minerals used within the same industry or related minerals that serve as substitutes by another country.
- Congress direct the National Science Foundation, in coordination with other agencies, to conduct a study on the impact of the activities of Chinese government, state-sponsored organizations, or entities affiliated or supported by the state in international bodies engaged in developing and setting standards for emerging technologies. The study should examine whether standards are being designed to promote Chinese government interests to the exclusion of other participants.

Introduction

Emerging technologies like AI, new and advanced materials, and new energy* have the potential to advance new products, disrupt established patterns of commerce, and alter established methods of military confrontation and deterrence. China's government has indicated clear intent to achieve technological leadership by promoting domestic firms, absorbing foreign technology, and localizing and monopolizing entire supply chains to establish technological self-sufficiency and strategic advantage. The objective of these policies is also achieved through other licit and illicit activities, such as extensive government subsidies, guarantees of substantial domestic market

*"New energy" is often used synonymously with "alternative energy" or "clean energy technology" in Chinese policy discussion, and refers to nonfossil fuel energy sources, including nuclear energy and renewables like wind and solar power, as well as energy storage technologies like lithium-ion batteries.

share for Chinese firms, and intellectual property theft. While these objectives and approaches are not new, China's economic planners continually modify strategies to capitalize on successes and eliminate methods that fail to deliver results.

Under General Secretary of the Chinese Communist Party (CCP) Xi Jinping, industrial policies increasingly aim to leverage the capabilities of China's most dynamic private firms for state-directed objectives through military-civil fusion. Loss of U.S. leadership in these areas—not only in research breakthroughs but also in application—could impact the United States' economic vitality, ability to project military power, and influence in international standards-setting and governance for future generations of these technologies.

This section assesses China's current capabilities and policy objectives in AI, new materials, and new energy, and identifies challenges China poses to U.S. interests in these sectors. It also describes China's progress in military-civil fusion, focusing on its impact in these sectors. It draws from the Commission's June 2019 hearing on "Technology, Trade, and Military-Civil Fusion"; contracted research; consultations with government officials, industry experts, and academics; and open source research and analysis.

Military-Civil Fusion

Ideological Foundations and Evolution of Military-Civil Fusion under General Secretary Xi

As a national strategy, military-civil fusion traces roots to the Maoist idea of "people's warfare," which prescribed a "whole-of-society" approach to military mobilization, and builds on industrial policy to drive military modernization.[1] China's economic planners and military strategists also looked to the United States' Defense Advanced Research Projects Agency (DARPA) as a model for promoting military innovation by harnessing corporate research and development (R&D).[2]

Mass civilian mobilization and defense industrial planning were synthesized in "military-civil integration," which gained traction during the 2000s, but struggled to overcome monopoly interests, bureaucratic fragmentation, and outdated contracting administration within China's defense economy.[3] The initiative made limited inroads in the electronics, information technology, high-technology, and automotive sectors, and precipitated removal of barriers to civilian participation in defense research, development, and acquisition, as well as private investment in naval and aerospace weapons systems development.[4]

From Military-Civil Integration to Military-Civil Fusion

China's program of military-civil integration was an earlier effort to foster ties between the civilian economy and China's defense industrial base. It primarily sought to address obstacles to military modernization and defense enterprise restructuring that arose from China's economic liberalization in the 1980s and 1990s in two stages: (1) retooling defense enterprises to produce consumer goods; and (2) encouraging advances in commercial technology to "spin on" into military application.[5]

From Military-Civil Integration to Military-Civil Fusion—*Continued*

- *Retooling defense enterprises to produce consumer goods:* During China's "reform and opening up" period in the 1980s, China's economic planners sought to revitalize the defense sector by encouraging firms to produce consumer goods like automobiles.[6] This initiative had limited success, as Chinese defense firms remained closely linked to government administration and driven by procurement practices in the planned economy, whereas civilian enterprises benefitted from new management approaches and foreign partnerships.[7] Successes in China's shipbuilding and electronics industries were notable exceptions.[8]
- *Encouraging advances in commercial technology to "spin on" into military application:* By the late 1990s, much of the technological advancement occurring in China's economy was driven by foreign-controlled production facilities and R&D centers located in China. China's government hoped participation in commercial production would enable China's defense manufacturers to acquire key dual-use technologies in fields like aerospace, microelectronics, new materials, and advanced manufacturing.[9] To achieve this goal, the government encouraged defense firms, except those exclusively focused on military production, to devote more business units to civilian production and establish more foreign partnerships.[10]

In its current iteration, military-civil fusion continues these objectives but is distinct in breadth and implementation. While military-civil integration focused primarily on restructuring and improving the technological know-how of China's defense sector, military-civil fusion is society-wide in scope, and extends much more deeply into China's civilian research institutions, as well as its startup ecosystem, the latter of which did not exist when military-civil integration was first conceived.[11] In practice, execution has evolved with China's industrial policy implementation to rely on a diverse pool of government-guided investment funds rather than top-down administrative decisions carried out by agencies and state-owned enterprises.[12]

Since taking power in 2012, General Secretary Xi has redoubled and refined this effort, placing it at the intersection of a broader military structure overhaul (see Chapter 4, Section 1, "Beijing's 'World-Class' Military Goal") and overarching industrial and innovation policy changes.[13] Rebranded "military-civil fusion," explicit efforts to foster ties between civilian enterprises and the military are contained within Made in China 2025,* the 13th Five-Year Plan,

*Made in China 2025 is an industrial policy and signature domestic economic policy of General Secretary Xi. Released in 2015, it outlines a ten-year plan to drastically increase domestic sources of essential components like semiconductors and achieve substantial progress in ten core industries through funding and policy support: (1) advanced information technology; (2) robotics and automated machine tools; (3) aircraft and aircraft components; (4) maritime vessels and marine engineering equipment; (5) advanced rail equipment; (6) new energy vehicles; (7) electrical generation and transmission equipment; (8) agricultural machinery and equipment; (9) new and China's AI strategy. In 2017, General Secretary Xi created a special oversight body to facilitate interagency coordination, the Central Commission for Integrated Military and Civilian Development, which he chairs.[14] General Secretary Xi's leadership of the commission signals military-civil fusion's intended centrality in defense industrial planning, but also underscores the need for strong authority to overcome bureaucratic hurdles in implementation.[15]

Military-Civil Fusion Policy Framework and Implementation

General Secretary Xi's vision of military-civil fusion, as articulated in numerous speeches, aims to fulfill three strategic objectives: (1) facilitate transfers between the defense and civilian sectors to improve the sophistication of China's military technology, particularly in sectors critical to informationized warfare;* (2) create cohesion in Chinese industry and academia working with and in support of military objectives, so that the entire system can be effectively mobilized to support the military in the future; and (3) drive technological innovation and economic growth.[16] To realize military-civil fusion, China's government has encouraged agencies and provincial and local governments to launch hybrid state-backed and private funds to guide military-civil fusion implementation, designated specific industries or types of technology for cooperative development between the civilian and defense sectors, and streamlined regulatory frameworks to facilitate ease of information flows and coordination between sectors.[17] These measures are in addition to significant government funding for other supporting efforts.

While China's government has pursued comprehensive tech plans in the past, military-civil fusion differs from preceding initiatives in blending private funding with state resources and leveraging existing capacity rather than attempting to build capabilities from scratch.[18] Military-civil fusion implementation also benefits from China's evolving approach to industrial policy. Since 2006, Chinese economic planners have largely shifted from a narrow focus on production targets to multipronged approaches requiring coordination between different agencies.[19] While the former often resulted in oversupply of inferior technology, newer policy frameworks attempt

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materials; and (10) pharmaceuticals and advanced medical devices. After Made in China 2025 became a focus of the Office of U.S. Trade Representative's Section 301 investigation into China's trade practices, Chinese officials ordered state media to cease mention of Made in China 2025 and removed it from the 2019 Government Work Report. Through careful analysis of supplementary policies, pilot programs, and changes in rhetoric, a July 2019 study of Made in China 2025's implementation by the Mercator Institute for Chinese Studies (MERICS) concluded that the industrial policy's implementation has continued unabated and policymakers have no intention of abandoning the plan. Max J. Zenglein and Anna Holzmann, "Evolving Made in China 2025: China's Industrial Policy in the Quest for Global Tech Leadership," *Mercator Institute for Chinese Studies*, July 2, 2019, 8–9, 29–33, 73; Sidney Leng and Zheng Yangpeng, "Beijing Tries to Play Down 'Made in China 2025' as Donald Trump Escalates Trade Hostilities," *South China Morning Post*, June 26, 2018; Office of the U.S. Trade Representative, *Findings of the Investigation into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation under Section 301 of the Trade Act of 1974*, March 22, 2018, 14–15; Zhu Minghao, "Becoming a Manufacturing Power Requires First Correcting a Deficiency in Core Components (实现制造强国须先弥补基础短板)," *China Industry Review*, August 3, 2015. Translation.

*"Informationized warfare" is a term used by the People's Liberation Army (PLA) to describe the incorporation of information technology into every facet of warfare. China's 2004 Defense White Paper emphasized the ubiquitous application of microelectronics and integration of information from various systems (e.g., logistics, intelligence collection, etc.). Where previous technological advances had shifted decisive force from quantity to quality of strike capabilities through improvements in precision, informationization changed the dynamic to a competition between "systems of systems." U.S.-China Economic and Security Review Commission, *Hearing on a "World-Class" Military*, written testimony of Dean Cheng, June 20, 2019, 2–3.

to foster market demand while establishing production capacity and lower prices through economies of scale and industry consolidation.[20] For instance, China's government has built a domestic new energy vehicle market through preferential procurement policies, consumer rebates, policy support for charging stations in major cities, higher industry standards to filter out small inefficient producers, and production quotas for auto manufacturers.[21]

The central government provided an overarching framework for military-civil fusion, and a small number of provincial and local governments have taken the lead in implementation, providing policy direction and funding. At the same time, an increasing number of universities and enterprises are reorienting to develop defense or dual-use technologies, often in partnership with military-affiliated research institutes.[22] As of 2019, more than ten provincial-level governments are investing tens of billions of dollars in production facilities, research, and support for overseas acquisitions through "guidance funds," according to analysis from asset manager AVIC Securities.[23] Administered by government agencies, these financing vehicles pool state funding and private capital to make investments that fulfill policy objectives, such as early-stage investments in startups that can provide technology to the People's Liberation Army (PLA), while also pursuing market returns.[24]

Local governments have also launched industry organizations or other initiatives that capitalize on their respective strengths or existing endowments. For instance, Zhongguancun, a tech hub in Beijing, created a Military-Civil Fusion Industry Alliance as early as 2014 that now counts 600 members.[25] In 2017, the alliance hosted a contest judged by 78 military experts to advance applications of AI, new materials, and new energy, among other fields.[26] Similarly, the northeastern port city of Tianjin, which leads China's supercomputer development, established an AI Military-Civil Fusion Innovation Center next to its National Supercomputer Center in coordination with the Academy of Military Science.[27] The city also has plans to establish partnerships with two other military institutes and is exploring providing cloud services for China's military.[28]

Talent Recruitment and Knowledge Transfer in Military-Civil Fusion

General Secretary Xi has emphasized the centrality of cultivating and attracting talent to support innovation in dual-use technologies.[29] Through initiatives like the Thousand Talents Program,* Chinese institutions provide foreign scientists and engineers generous compensation (e.g., a onetime "signing bonus" of $151,000 and research stipends ranging from $453,000 to $755,000 for established scientists over the age of 40), and equip them with cutting-edge

*The Thousand Talents program is a government effort launched in 2008 to recruit foreign talent. Initially, it targeted overseas Chinese, but quickly expanded to include all foreigners, and developed offshoots targeting up-and-coming researchers in addition to its initial focus on established professionals. Foreigners accepted into the Thousand Talents program must already have positions in China, and receive bonuses and research funding in addition to their compensation through Chinese institutions, as well as reduced administrative barriers to establishing residence in China. Hepeng Jia, "China's Plan to Recruit Talented Researchers," *Nature* 553: S8 (January 17, 2018), Zhai Lixin, "Give Play to the Talent Management Reform Pilot Zone's Pioneering Function and Accelerate the Construction of a Science and Technology Center with Global Influence (发挥人才管理改革试验区先行先试作用加快建设具有全球影响力的科技创新中心)," *Yearbook of Zhongguancun 2018*, 7–8. Translation.

facilities to conduct research in China.[30] In some cases, foreign scientists are permitted to maintain overseas affiliations and set up labs that mirror their U.S. facilities.[31] As of September 2017, the Thousand Talents Program had recruited about 7,000 people, according to China's Ministry of Human Resources and Social Security.[32] Zhongguancun's 2018 Yearbook claims 1,180 recruits from the Thousand Talents Program are associated with the Beijing tech hub alone, attributing this high volume to a network of ten overseas recruitment centers and programs to place foreign talent in Beijing.[33]

China's Ministry of Science and Technology has sought to place recruiters within U.S. institutions under disguise as researchers. According to charges unsealed by the Department of Justice on September 16, 2019, since 2017 an official operating the New York office of the China Association for International Exchange of Personnel (an agency under China's Ministry of Science and Technology) conspired to fraudulently obtain visas for recruiters to pose as visiting academic researchers while seeking to attract U.S. talent back to China.[34]

Chinese institutions have also tried to facilitate knowledge transfers by sending Chinese researchers to foreign universities, often disguising their military affiliations.[35] A report from the Australian Strategic Policy Institute (ASPI) details the extensive practice of creating "cover institutions" that exist only on paper, and through which PLA-affiliated researchers portrayed themselves as civilian academics to attend conferences or participate in exchanges overseas.[36] Of more than 2,500 military scientists and engineers who have gone abroad since 2007, the report found at least dozens have used false credentials to work in sensitive areas, such as hypersonic missiles and navigation.[37] In other cases, the rewards for economic espionage incentivize Chinese students in the United States to steal research to boost their chances of successful application to talent programs.[38]

As part of military-civil fusion, Chinese firms obtain dual-use technologies through overseas acquisitions supported by government funding.[39] For instance, since its creation in 2008, state-owned defense conglomerate Aviation Industry Corporation of China (AVIC) has spent at least $3.3 billion acquiring at least 20 aerospace, automotive, and engineering firms, mainly in the United States and Europe.[40] These acquisitions were supported by China Construction Bank and Tianjin Municipal Government.[41] Government guidance funds with military-civil fusion investments are also funding R&D centers abroad, including Zhongguancun Capital's innovation centers in San Francisco, Boston, and Heidelberg.[42]

Military-Civil Fusion Tied to Chinese Venture Capital Funds and R&D Centers Abroad

R&D centers and incubators* such as those tied to Zhongguancun Capital have complex and amorphous links to U.S. academ-

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*Incubators and accelerators focus on seed stage investments, or providing startup founders nominal initial funding, work space, expertise, and other resources to prove an initial business concept. In contrast, VC firms typically invest in companies that have already launched operations to help them expand their product offerings and reach a broader market. Often incubators will try to connect successful projects with VC firms. Incubators and investment funds tied to China have encouraged projects launched in the United States to migrate to China for successive stages of product development and venture funding. Office of the U.S. Trade Representative,

Military-Civil Fusion Tied to Chinese Venture Capital Funds and R&D Centers Abroad—*Continued*

ic institutions and often have an explicit goal of helping firms license technology or attract joint ventures and talent to China.[43] First among such funds was Zhongguancun-Stanford New Technology Venture Investment Fund, established in 2013, which by 2017 had raised $91.3 million to spin off projects started at Stanford and other U.S. institutions and provide assistance with market access in China.[44] A VC fund controlled by eastern city Hangzhou, home to Alibaba, similarly established an incubator in Redwood City, California, in 2014. Within less than three years, the fund attracted 41 projects and planned ventures to Hangzhou.[45] The range and scale of projects supported by Chinese government-funded R&D centers is substantial. For example, Zhongguancun Capital's Boston-based incubator Z-park and Silicon Valley R&D center claim to "collect nearly 4,000 projects in the [United States] annually" in biotechnology, artificial intelligence, information technology, and other fields into a database of possible investments.* [46]

Chinese government VC funds and R&D centers support technologies and projects with clear national defense implications. Danhua Capital, backed by Zhongguancun Capital, has investments in Cohesity, a data management and security company that services the U.S. Department of Energy and U.S. Air Force, and also owns a minority stake in U.S. drone maker Flirtey, which was selected in May 2018 to work with the U.S. Department of Transportation to integrate drones into U.S. airspace.[47]

The Chinese government has also promoted scientific collaboration as a key element of the Belt and Road Initiative (BRI) in ways that could further leverage civilian research to support military advancement.[48] The April 2019 Belt and Road Forum announced an international scientific alliance with 37 countries, numerous other agreements between state science organizations with both developed and developing countries, and programs to bring graduate students to China.[49] China's State Council† aims to use scientific and

"Findings of the Investigation into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation Under Section 301 of the Trade Act of 1974," March 22, 2018, 147; Yang Fan, "ZDG Establishes First Overseas Technology Investment Fund," *China Daily*, June 8, 2013.

*Z-Park does not clarify how many of these applications it reviews, provides a workspace for, or funds. For comparison, *New York Times Magazine* reported Silicon Valley accelerator Y Combinator received around 2,633 for its semiannual cycle in the first half of 2013, of which it provided 47 with $100,000 each in funding. Nathaniel Rich, "Silicon Valley's Start-Up Machine," *New York Times Magazine*, May 2, 2013.

†China's State Council is a government body composed of China's 26 ministry-level bodies and other state agencies such as the Chinese Academy of Sciences and the State-owned Assets Supervision and Administration Commission, which oversees China's state-owned enterprises. It is overseen by ten State Councilors, all of whom are senior CCP members, and run by the premier of China. Among other functions, the State Council is generally responsible for day-to-day economic decision making, but under General Secretary Xi, Premier Li Keqiang and the State Council have largely been sidelined in determining the course of economic policymaking, in favor of leading small groups chaired by General Secretary Xi. U.S.-China Economic and Security Review Commission, *Hearing on What Keeps Xi Up at Night*, written testimony of Jude Blanchette, February 7, 2019, 1–3; State Council of the People's Republic of China, *State Council Organizational Structure* (国务院组织机构). Translation; State Council of the People's Republic of China, *State Council Leadership* (国务院领导). Translation.

technological cooperation through BRI to improve China's nuclear power and aerospace technology, and calls for increasing high-tech arms exports to BRI countries.[50] A 2017 article in *Red Flag Manuscript*, a publication associated with the CCP journal *Seeking Truth*, urges using BRI's talent exchange platforms to "serve military-civil fusion."[51] The author, a political researcher at China's largest think tank, argues that an inter-agency plan for scientific collaboration along BRI could allow educational resources to support dual-use technology innovation and suggests establishing a system of policies for BRI to better serve military-civil fusion.[52]

Artificial Intelligence

AI is an umbrella term for computing applications that involve machine perception or automating complex decision-making processes, typically through machine learning or recognizing patterns in data (see Addendum I).[53] As a general purpose technology, AI has been likened to electricity in its potential transformative impact: applications of AI will extend to many sectors of the economy; the underlying technology will continuously improve; and AI will enable many other innovations.[54] Technological advancement in AI relies on increases in computing power, sophistication of algorithms, and availability of data on which to train those algorithms.[55]

China's Policy Objectives and Current Capabilities in AI

Policy Background

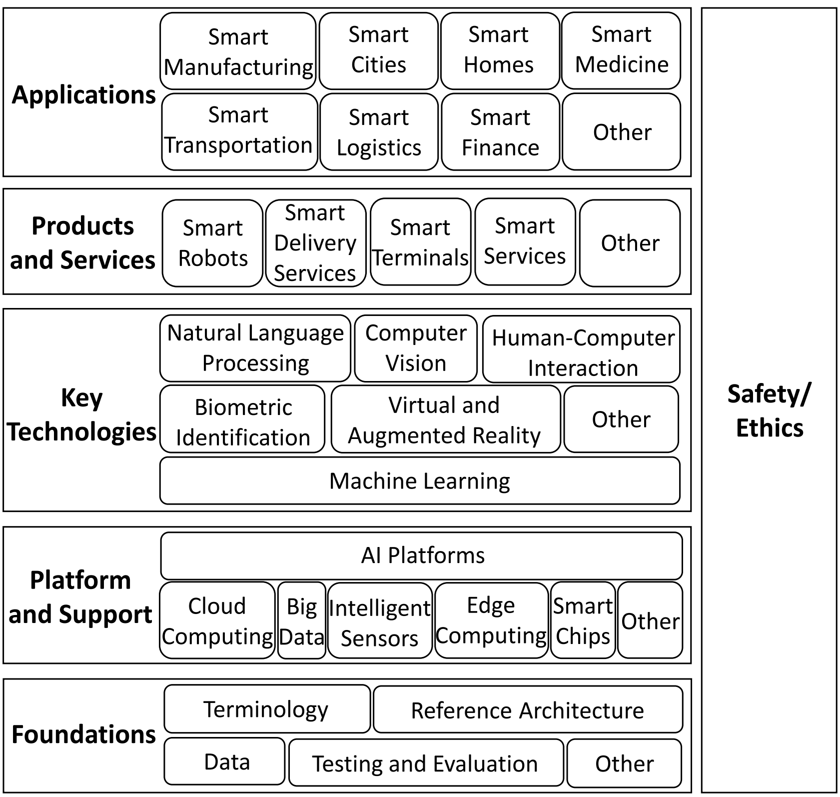
In 2017, the State Council released the Next Generation AI Development Plan, making AI a centerpiece of China's development strategy.[56] The Next Generation AI Development Plan sets ambitious milestones, calling for China to establish parity with other advanced economies in AI by 2020 and become a global leader in AI theory, technology, and applications by 2030. It also targets tenfold growth of AI industry gross output (including from AI applications) during those ten years, from $150 billion in 2020 to $1.5 trillion by 2030.[57] In testimony before the Commission, Jeffrey Ding, China lead at the Future of Humanity Institute's Center for AI Governance, noted that China's approach to AI rests on three principles: (1) central planning guides local implementation, and provincial and local governments have broad leeway to pursue various objectives within the overall framework provided in the plan; (2) setting international technical standards for AI is a priority, both to build more reliable AI-enabled systems and influence international norms to China's strategic and economic advantage (Figure 1 outlines China's approach to AI standards); and (3) recruiting and training top AI talent are dual objectives for guaranteeing China's long-term competitiveness.[58]

The 2017 Next Generation AI Development Plan marked a shift in China's approach to AI, from pursuing specific applications to prioritizing AI as foundational to overall economic competitiveness. The "centrally guided, locally implemented" framework has allowed Chinese policies to absorb and build on previous industrial policies that provide a foundation for quickly applying AI solutions to existing initiatives, such as upgrading industrial robotics promoted in

Made in China 2025 to support machine vision and autonomous decision making.[59] Fifteen of 31 provincial-level governments released their own AI plans by the end of March 2018, targeting gross industry output of $429 billion by 2020, or nearly three times the national target of $150 billion for the same period.[60]

China Electronic Standardization Institute, a standards-making body under the Ministry of Industry and Information Technology, also led over 30 institutions and companies in drafting a white paper to coordinate AI standards development, published in January 2018 (see Figure 1).[61] The white paper frames an especially broad approach to AI standards-setting, extending beyond AI technologies like computer vision* or natural language processing to encompass foundational elements of computing that underpin AI, as well as products and services that incorporate AI applications.[62]

Figure 1: China's Approach to AI Standards



Note: The Chinese government released an AI Standards White Paper in January 2018 outlining an especially broad approach to AI-standards setting aimed at integrating AI into existing fields.

Source: Adapted from Jeffrey Ding et al., "Chinese Interests Take a Big Seat at the AI Governance Table," *New America*, June 20, 2018.

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*Computer vision is any computational process to identify patterns in images, such as facial recognition in surveillance system or smartphone locks, or object detection such as autonomous vehicles recognizing stop signs.

These plans and standards guidelines build on the progress of earlier policy initiatives to improve digital infrastructure. These initiatives have provided a technological foundation for quickly advancing AI subdomains.* For example, creating numerous cameras and sensors to monitor traffic conditions as part of China's smart cities development program now provides the data for urban management systems like Alibaba's City Brain in Hangzhou, which uses AI to monitor and redirect traffic to reduce congestion.[63]

Industry Overview

China has emerged as a leader in several subdomains of AI, in particular computer vision, digital lifestyle products (e.g., ride hailing and delivery applications), robotics, and speech recognition.[64] China is ahead of or on par with the United States in technologies that are poised for transformational growth from the application of AI, such as commercial and military strike-capable drones incorporating autonomous navigation.[65] China trails the United States in autonomous vehicle (AV) technology but is rapidly catching up.[66]

Many Chinese AI companies that appear most competitive vis-à-vis the United States are an outgrowth of the country's broad adaption of mobile internet and use of mobile applications,† which gives China's leading mobile platforms like Baidu, Alibaba, and Tencent unparalleled access to consumer data.[67] By contrast, China's advances in industrial robotics have been driven by extensive government support and overseas acquisitions,‡ as well as some spillover from major international robot manufacturers locating production facilities in China.[68]

Computer vision falls somewhere in between, with private funding responding to a demand created by government policy. Chinese image recognition startups outperform and are far better funded than international peers, but China's Ministry of Public Security is a primary customer for facial recognition in surveillance systems and the National Development and Reform Commission, an economic planning agency, has issued policy encouraging use of AI in facial recognition.[69] China's widespread use of surveillance applications of

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*For instance, the white paper includes an appendix of ten applications of AI by Chinese companies to provide a template for different AI standards, but these technologies were in many cases supported by earlier industrial policies. In intelligent manufacturing, the white paper champions Haier's COSMOplat, a customizable manufacturing execution and supply chain management system that was developed under Made in China 2025. Standards Administration of China and China Electronic Standardization Institute, *White Paper on Artificial Intelligence Standardization* (人工智能标准化白皮书), January 2018, 96–98. Translation.

†China's mobile internet ecosystem developed with minimal competition from foreign firms due to mandated government monopolies in telecommunications, the Golden Shield Project (popularly known as the "Great Firewall") which prohibits access to popular foreign sites like Google and Facebook from within mainland China's borders, strict licensing requirements for provision of content over the internet, including via mobile applications, and increasingly demanding regulations on management of user data. Hugo Butcher Piat, "Navigating the Internet in China: Top Concerns for Foreign Businesses," *China Briefing*, March 12, 2019; Ashwin Kaja and Eric Carlson, "China Issues New Rules for Mobile Apps," *Inside Piracy*, July 1, 2016.

‡Chinese state-owned enterprises have concluded several major acquisitions of robotics and automation firms since Made in China 2025 encouraged closing China's technological gap through acquiring foreign firms, including Chinese air conditioner and refrigerator manufacturer Midea Group's acquisition of a majority stake in German robot maker Kuka AG, the world's largest producer of robots used in auto factories. U.S.-China Economic and Security Review Commission, *Hearing on Technology, Trade, and Military-Civil Fusion*, written testimony of Dan Coughlin, June 7, 2019, 4; Sun Congying, "Midea, Kuka Chase Automation Dreams with $1.6 Billion Park," *Caixin*, March 29, 2018; Sun Yuyao, "Overseas Mergers and Acquisitions: Chinese Manufacturing Integrates into the Global Industrial System (海外并购井喷 中国制造融入全球产业体系)," *Advanced Manufacturing Daily*, December 29, 2012.

AI is driven in large part by the absence of privacy protections and by government repression of ethnic groups.[70] For example, law enforcement agencies across China are deploying facial recognition to identify and track Uyghurs, a Muslim minority from northwestern Xinjiang Province.[71]

Both the government and private sector are substantial investors in China's AI. In their AI development plans, the municipal governments of Shanghai and Tianjin each pledge to invest $15 billion in AI, close to Google's parent Alphabet's $16.6 billion in global R&D expenditure during 2017.* [72] However, China's government guidance funds do not always raise or spend the money as planned due to a shortage of investors, inability to recruit qualified personnel to manage the funds, and lack of investment targets that meet the funds' investment criteria, among other reasons.[73] Nonetheless, in startup funding, technology market research firm CB Insights estimates that Chinese companies (including Hong Kong-based companies) received 48 percent of global AI equity investment in 2017, ahead of the United States' 38 percent and up from 11 percent in 2016.[74] A handful of large foreign VC groups like Japanese conglomerate SoftBank and U.S. VC firm Sequoia are active investors in China's AI market.[75]

China's AI "National Team"

In November 2017, China's Ministry of Science and Technology selected Baidu, Alibaba, and Tencent, as well as voice recognition firm iFlytek, to form a "National Team" charged with developing AI in a range of subdomains.† [76] According to the government plan, Baidu is to focus on autonomous driving, Alibaba is to focus on cloud computing and smart cities, Tencent is to focus on AI-powered medical diagnosis, and iFlytek is to continue working on voice intelligence.[77] Hong Kong-based facial recognition startup SenseTime was subsequently tapped to focus on intelligent vision.[78]

In both design and execution, the national team approach differs from overt promotion of national champions.‡ None of the firms are state-owned and all had established capabilities in their assigned subdomains before being selected.[79] In some respects,

*Alphabet's financial disclosures do not distinguish investments in AI from other capabilities and products, but it is likely the world's largest corporate spender on AI. Alphabet Inc., *Form 10-K for the Fiscal Year Ended December 31, 2017*, February 5, 2018, 36; *Economist*, "Google Leads in the Race to Dominate Artificial Intelligence," December 7, 2017.

†Chinese agencies have occasionally designated a "national team" of companies with preexisting capabilities to focus on building up capacity in a particular field, such as the Ministry of Commerce's 2010 policy to support well-established brick and mortar retailers in developing e-commerce operations. Companies in a national team do not receive anticompetitive policy support to the extent of national champions and have more autonomy to pursue business avenues other than those directed by the government. U.S.-China Economic and Security Review Commission, *Hearing on Technology, Trade and Military-Civil Fusion*, written testimony of Jeffrey Ding, June 7, 2019, 8. Tencent Technology, "China's Ministry of Commerce's Support for Three Large Companies in the 'Ecommerce National Team' Revealed (商务部扶持电子商务"国家队"三大企业曝光)," *China Information Industry Network*, March 3, 2010. Translation.

‡National champions are large, often state-owned firms that advance state interests, whether to establish capacity in a new sector or become competitive internationally in a particular sector. Typically, they receive policy support to assist in advancing state objectives, including subsidies, tax credits, guaranteed market share or monopoly access in certain industries, and supportive regulation and financing to acquire or displace smaller competitors or vertically integrate within other functions of an industry.

China's AI "National Team"—*Continued*

they also compete with each other. For instance, Baidu, Alibaba, and Tencent are still developing computer vision capabilities despite SenseTime's designation as the intelligent vision leader.[80] At the same time, the national team approach clearly signals that these AI subdomains are policy priorities, reducing regulatory barriers to developing new technologies, improving access to funding, and possibly diminishing market vitality by priveleging national team incumbents and posing challenges to industry latecomers.[81]

U.S.-China Competition in AI

While Chinese firms are excelling at many subdomains of AI, the United States is ahead in key inputs like talent and corporate R&D funding, and maintains a decisive lead in the foundational platform and support architectures that underpin many AI technologies and applications.[*] [82] Taken together, these advantages place the United States ahead of China's overall AI capabilities, but China's market structure and government intervention may undermine the U.S. lead.

Multiple studies of international AI talent distribution place the United States firmly in the lead, particularly in experts capable of pushing the technological horizon forward.[83] To the extent that China is catching up, it is mostly training engineers and developers capable of using existing AI software packages, rather than breaking new ground.[84] The United States is also far ahead in corporate R&D expenditure, counting 12 out of the top-spending 20 software and computer services firms globally in 2018, versus three in China.[†] While Chinese researchers publish and patent more in total than U.S. researchers, far fewer Chinese articles are accepted into the most prestigious scientific journals and conferences or rank among the most highly cited papers, and a much lower proportion of Chinese AI patents are accepted at patent offices outside of China.[85]

Beyond these basic indicators, U.S. institutions develop and maintain the majority of foundational platform and support architectures upon which AI technologies and applications are built. Analysis of 93 widely used open source AI software platforms by the Ministry of Industry and Information Technology (MIIT) finds 61 of the platforms were developed by organizations based in the United States, compared to only 12 developed by institutions or individuals based

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*Architectures guide how computers process information, from chip architectures that control how software interfaces with hardware, to information architecture like metadata, which instruct computers on how to organize data. Platforms provide ready-made toolkits that allow AI application developers to deploy and tailor premade AI algorithms toward specific problems, rather than always having to write code from scratch. Rob Thomas, "The Road to AI Leads through Information Architecture," *Venture Beat*, January 12, 2018; Mike Williams, "5 of the Best AI platforms for Business," *TechRadar*, January 10, 2018; Mostafa Abd-El-Barr and Hesham El-Rewini, *Fundamentals of Computer Organization and Architecture*, Wiley-Interscience, 2005, 1–6.

†R&D expenditure at these firms extends beyond AI, but spending patterns by software and computer services firms are indicative of corporate investment in AI. U.S.-China Economic and Security Review Commission, *Hearing on Technology, Trade and Military-Civil Fusion*, written testimony of Jeffrey Ding, June 7, 2019, 3; Timothy W. Martin, "American Tech Firms Are Winning the R&D Spending Race with China," *Wall Street Journal*, October 30, 2018; *Economist*, "Google Leads in the Race to Dominate Artificial Intelligence," December 7, 2017.

in China.*[86] These architectures and open source platforms serve as de facto standards for global AI development, and extend the influence of U.S. firms in shaping how AI evolves.[87] The United States also leads in some of the most critical subdomains of AI, such as potentially lucrative AVs, as well as many business applications of AI.[88]

While the development of these capabilities are mostly driven by the private sector, the U.S. government holds a convening role in bringing together industry, government, and academia in setting research priorities and balancing AI development with security. Following the February 2019 Executive Order on Maintaining American Leadership in Artificial Intelligence, the National Institute of Standards and Technology (NIST) is coordinating between federal agencies and the private sector to develop technical standards to ensure systems using AI are robust, secure, and reliable.[89]

Despite the United States' strong positioning in AI, China's government intervention, market structure, and construction of AI-enabling infrastructure affords Chinese AI firms unfair advantages. China's selection of an AI National Team encourages some degree of competition, but also clearly designates and provides support for certain companies to become champions in particular AI subdomains.[90] Their reduced need to defend market share enables them to allocate greater resources to R&D.[91] The sheer size of China's market and diversity of consumer exposure to digital platforms powered by major tech conglomerates also provide these firms with both greater breadth and depth of data than U.S. competitors.† For some subdomains of AI, such as healthcare applications, China's strict data transfer regulations limit or outright prohibit U.S. firms' access to Chinese data, while Chinese firms have broad access to U.S. data.[92] Lastly, China may leapfrog the United States in applications of AI that require major infrastructure changes and strong national coordination. For instance, the smart city pilot Xiongan, just outside Beijing, will have a section that only allows AVs, creating an unprecedented testing ground.[93]

The nature of global advances in AI also makes assessing national capabilities difficult, as both commercial and theoretical AI development are driven by exceptionally open publication and information-sharing norms. While the openness of the AI research community benefits latecomers like China because they do not need to spend their own capital to reach a minimum baseline for any technology, the research culture and de facto standards are still driven by the dominant institutions, which are almost exclusively located or headquartered in the United States. Talent is also drawn to the

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*Widely adopted open source software can amount to de facto industry standards. For instance, in 2014 Google decided to make part of its proprietary machine learning library open source. Called TensorFlow, this library has evolved into a community—composed of AI developers and researchers—in which participants are highly incentivized to share findings and agree on definitions and standardized documentation. The library is now used by many major enterprises. U.S.-China Economic and Security Review Commission, *Hearing on Technology, Trade and Military-Civil Fusion*, written testimony of Helen Toner, June 7, 2019, 8; Rajat Monga, *Artificial Intelligence (AI) Podcast*, Podcast, June 3, 2019.

†For instance, Alibaba Group and its subsidiaries may serve as a consumer's primary means to shop online, pay for both digital and physical goods through other vendors, pay for utilities, invest short-term savings, and watch videos online. It has also invested in online healthcare services. Nicole Jao, "Briefing: Alibaba Health gets a $290 million boost from Alibaba, Ant Financial," *Technode*, May 24, 2019; Ming Zeng, "Alibaba and the Future of Business," *Harvard Business Review*, September–October 2018.

environment created by dominant institutions because they serve as a platform to influence global AI development, whereas the Chinese AI environment is generally more focused on commercialization of existing techniques.[94] Nonetheless, China's government may compel firms to pursue its strategic priorities, effectively guiding the focus of AI application through policy incentives, or mandates. The government can also use less formal channels of influence such as leveraging CCP cells, which all firms are required to have, or assigning local officials to oversee ostensibly private companies.[95] It may also shape the evolution of AI by guaranteeing a market for new applications to overcome an initial lack of commercial interest.[96] By contrast, the U.S. government has fewer means and limited support for directing the activity of multinational firms headquartered in the United States.

Military-Civil Fusion and AI

Lieutenant General Liu Guozhi, director of the Science and Technology Commission within China's Central Military Commission, believes AI is a turning point at which China could catch up to and surpass the United States in the next generation of warfare.[97] China's strategists see AI as a force multiplier across systems, a potential asymmetric advantage against high-value conventional weapons systems, and even a harbinger of a new mode of combat, where superior algorithms prove operationally decisive.[98] Developing AI-enabled military systems dovetails with the PLA's push to improve coordination across domains through information networks—both priorities stressed by General Secretary Xi in his October 2017 report to the 19th Party Congress.[*][99]

New and Advanced Materials

New materials are synthetically derived materials that often have properties not found in nature (e.g., the ability to not reflect light) or greatly enhanced properties found in nature (e.g., conductivity, flexibility, and strength). In research labs, the descriptor "new" distinguishes new materials from traditional metals, plastics, and ceramics.[100] New materials' applications are virtually unlimited, from improving the strength and durability of pedestrian materials like concrete, to enabling biomedical breakthroughs like regrowth of damaged nervous tissue (see Addendum II).[101]

Unlike AI, where major advances with commercial impact have mostly occurred within the last decade, materials science has been fundamental to many industrial advances since it emerged in the 1950s (e.g., in fiberglass widely used in automobile bodies and interiors, or anticorrosive materials used to preserve steel in ship hulls).[102] The field relies on expensive equipment and specialized knowledge to synthesize and manufacture new materials, and higher-value applications† like aerospace and automobile manufacturing

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*PLA strategists refer to these systems as "intelligentized," including systems that are partially or fully autonomous or in which AI augments human abilities, including enhancing or replacing human decision making in command and control. U.S.-China Economic and Security Review Commission, *Hearing on China's Advanced Weapons*, written testimony of Elsa Kania, February 23, 2017, 17, 19–20.

†In order of decreasing technological intensity (i.e., amount of scientific knowledge required to increase productivity), major industries include aerospace and defense, automotive, electronics, marine applications, construction, and sporting goods. U.S.-China Economic and Security Review

have coevolved with advances in computing, machine tooling, and industrial robotics to apply scientific breakthroughs in new materials on the factory floor at scale.[103]

Longer history and accumulation of technical know-how, close linkages between science and manufacturing, and high equipment costs create a steep learning curve for late entrants in new materials, but Chinese policymakers and firms have prioritized overcoming these barriers since the mid-1980s. Their success was initially limited to lower-value products like sporting goods, but improvements in China's machine tooling and robotics industries, fueled largely by foreign joint ventures and acquisitions, have enabled China to become competitive in more sophisticated applications. The risks to the United States are twofold and urgent: (1) China's robust manufacturing base supports innovations on the factory floor that advance commercial applications more than scientific breakthroughs; and (2) while other countries may continue to lead breakthrough discoveries in materials science, the Chinese government is providing extensive support for a scientific and industrial infrastructure to commercialize these discoveries ahead of other countries.

China's Policy Objectives and Current Capabilities in New Materials

Developing capabilities in new materials has been a staple of China's industrial policies, but emphasis has expanded from catching up in materials essential in dual-use applications like aerospace to a strategy of accelerating new materials used in disruptive technologies to gain a general technological edge. This shift in focus has been accompanied by overseas acquisitions that improve Chinese firms' use of new materials in manufacturing and policy support for materials science research.

The Chinese government first designated new materials as a priority area in the 863 Plan, an industrial policy launched in 1986 to jumpstart China's science and technology development.[104] Subsequently it incorporated them in five-year plans and in the seven areas targeted as Strategic Emerging Industries under Hu Jintao.[*] [105] These plans tended to focus on improving domestic capabilities in producing high-performance composites and fibers. Made in China 2025 promoted new materials as one of the core ten industries central to upgrading China's overall manufacturing capabilities. The most recent roadmap for implementation of Made in China 2025 divides these efforts by "advanced foundational new materials" such as those used in infrastructure, "key strategic new materials" such as those used in high-tech equipment, and "frontier new materials" such as those used in additive manufacturing.[106] From the 1980s, Chinese economic planners sought to catch up in manufacturing processes that utilize new materials, either through developing capabilities locally or obtaining foreign technology through legal ac-

Commission, *Hearing on Technology, Trade, and Military-Civil Fusion*, supplemental written testimony of Dan Coughlin, June 7, 2019, 7.

*The seven areas in the Strategic Emerging Industries initiative are: (1) energy-saving environmental industry, (2) new information technology, (3) biology, (4) high-end equipment manufacturing, (5) new energy, (6) new materials, and (7) new energy automobiles. Tai Ming Cheung et al., "Planning for Innovation: Understanding China's Plans for Technological, Energy, Industrial, and Defense Development," *University of California Institute on Global Conflict and Cooperation* (prepared for the U.S.-China Economic and Security Review Commission), July 28, 2016, 36.

quisition or theft. China counted notable early successes after the launch of the 863 Plan in less advanced materials, like carbon fiber used in sporting goods (e.g., fishing rods), but struggled to achieve breakthroughs due to lack of investment in basic research.[107]

As advanced industrialized countries located more factory assembly in China, domestic supply chains emerged for components used in electronics, consumer goods, and to some extent automotive and aerospace manufacturing. Integration into global supply chains and foreign joint ventures has enabled Chinese firms to steadily make inroads in materials used within these components. In other cases, Chinese economic policy prompted advances in materials used in wind mills and construction.[108]

While the United States has retained leadership in the most advanced manufacturing processes for materials used in aerospace manufacturing,* China's state-owned enterprises have actively sought to build a domestic aviation industry. They have succeeded in establishing a robust supply chain for aerospace components with the help of foreign firms. U.S. and European aerospace manufacturers have provided Chinese joint venture partners with machine tools and production techniques for building civilian aircraft parts, while firms like U.S. structural composites maker Hexcel have supplied advanced composite materials used in molding these parts.[109] For example, in 1998 Boeing and Hexcel established a joint venture with Chinese state-owned defense and aerospace conglomerate AVIC to manufacture both structural (e.g., wings and fuselage) and interior (e.g., doors and linings) parts for commercial aircraft.[110] Boeing bought Hexcel's stake in 2008, acquiring a majority in the joint venture and expanding production in 2011. The joint venture now produces parts for all of Boeing's commercial aircraft models, and also supplies local civil aviation firms.[111] Since 2015, Chinese firms have acquired several German aerospace materials companies, and ChemChina acquired German machining and tooling firm Krauss-Maffei.[112] AVIC has also sought to obtain licensing for advanced materials through overseas acquisitions.[113]

While these arrangements do not transfer high grade carbon fiber or advanced machine tools used in stealth aircraft, the cumulative knowledge and production techniques Chinese aerospace manufacturers have acquired through foreign partnerships and imports have equipped Chinese manufacturers both with the capability to synthesize high grade carbon fibers independently and build machine tools that compete with foreign producers. Chinese military contractors are now able to produce carbon fibers they would not be able to purchase from the United States because this type of material

*These advanced processes can be divided into three categories: (1) computer simulations of synthetic materials behavior at different atmospheric conditions before any manufacturing begins; (2) chemical and mechanical processes to synthesize and purify materials until they have desired properties (e.g., lightness, strength, resistance to heat), which are often closely guarded trade secrets; and (3) automated molding, casting, and other techniques to form materials into specific parts, which often use large robotics operating at precise temperatures and building to very exact specifications. Mary Jay Lou, "Rise of the Robots," *Composites Manufacturing*, September/October 2017, 24–28; *Aerospace Engineering*, "Composites Manufacturing," July 12, 2012; *Cincinnati Business Courier*, "MAG Sells First Composite Tape-laying System to China," February 15, 2012; Vicki McConnell, "The Making of Carbon Fiber," *Composites World*, December 19, 2008; Proceeding of the International SAMPE Symposium and Exhibition, "Advanced Technology Tape Laying for Affordable Manufacturing of Large Composite Structures," January 1, 2001.

is subject to export controls.[114] Nonetheless, Chinese producers are still behind the highest strength fibers.[115]

For the past decade, China's government has also broadened focus from catching up in industrial applications of new materials to being at the forefront of scientific discoveries by building research laboratories; training and recruiting researchers; and fostering collaboration between academia, industry, and the military.[116] State funding for materials science has quadrupled since 2008, and Chinese universities have been patenting research aggressively.[117] Patterns in patenting trends suggest Chinese researchers are a few years behind the United States, but are establishing foundational capabilities on par with global counterparts.[118] For instance, while graphene was first synthesized in the United Kingdom at the University of Manchester in 2004, China now accounts for 58 percent of global patents in graphene—with most of its patenting activity occurring in the last seven years.* [119] Universities lead graphene patenting in China while corporations hold most graphene patents in the United States, suggesting patenting has been driven by state interests in China.[120]

Unlike improvements in new materials widely used in manufacturing such as carbon fiber, scientific breakthroughs in materials like graphene hold more potential to lead to rapid and disruptive changes in technology. However, established applications hold much more market value currently—aerospace, which depends heavily on carbon fiber, is the United States' largest export.[121] Moreover, the timeframe for commercializing applications of cutting-edge materials is uncertain. As a result, U.S. manufacturers tend to rely on materials already in mass market use. By comparison, the Chinese government is providing support for firms to synthesize and use new materials, creating risk that U.S. firms continue to use old technology.

U.S.-China Competition in New Materials

The most imminent threat posed to the United States by the Chinese government's policy approach in materials science is not loss of absolute technological leadership, but loss of industries and manufacturing processes dependent on advances in new materials. National economic and strategic competitiveness in new materials is often driven by meeting demand from the industries that rely most heavily on new materials and the ability of those industries to integrate basic research discoveries into commercial application. However, it is also dependent on a country's manufacturing capabilities, not just within individual companies but across supply chains that take materials from raw ingredients to purified materials to finished parts.[122] Because many innovations in new materials are driven by adaptations in manufacturing processes rather than breakthroughs in laboratory research or design, countries with more manufacturing facilities are better positioned to commercialize advances in new materials.[123]

Although the United States has long held leadership in the most technologically intensive industries that use new materials, respon-

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* Graphene is single atomic layer of carbon, the element that has the strongest molecular bond. It has two forms: "lens," a single highly conductive and transparent atomic layer that has applications in electronics and optics; and "oxide," a powder of graphene crystals that can be used as a structural additive to strengthen other materials. U.S.-China Economic and Security Review Commission, *Hearing on Technology, Trade, and Military-Civil Fusion*, written testimony of Alan Hill, June 7, 2019, 1–2.

sibility for funding translational R&D falls principally on U.S. corporations,* which often prefer to conduct R&D in China due to its extensive manufacturing network and cheaper access to materials and components.[124] China's government, as well as governments of other advanced industrialized nations, are far more active in supporting R&D at this critical stage of commercialization than the United States.[125] Exact comparisons between Chinese and U.S. translational R&D spending are difficult due to differences in statistical categories and economic structure, but there are some representative examples.† In 2018, China's MIIT alone spent $3.5 billion (renminbi [RMB] 24.9 billion)‡ on applied R&D, which dwarfs the U.S. government's total $746 million on R&D related to industrial production and technology for the same year.§[126] The U.S. National Science Foundation reported that overall U.S. corporate spending on late stage R&D reached $277.6 billion in 2016, the latest year available.[127]

Notably, Chinese firms also leverage international cooperation to compensate for gaps in their capabilities, in particular benefiting from partnerships with German and South Korean firms.¶ The risk to U.S. competitiveness is particularly acute in emerging industries dependent on new materials that are poised for rapid development, like the urban air mobility market (e.g., delivery drones).[128] If the United States loses out on early stages of development, it could also cede influence in international standards setting, and may be forced to license technology from China or other countries.

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*Translational research focuses on developing applications of basic research. In the context of manufacturing and new materials, this typically involves developing prototypes, demonstrating manufacturability, and identifying viable markets. Sridhar Kota and Thomas C. Mahoney, "Manufacturing Prosperity: A Bold Strategy for National Wealth and Security," *Alliance for Manufacturing Foresight*, June 2018, 2, 42.

†Because China's corporate R&D statistics include state-owned enterprises, whose R&D activities can be directed by the state, it is difficult to distinguish corporate from government R&D expenditure in China. In assessing the allocation of government R&D subsidies, a 2014 Center for European Economic Research study even found that China's government subsidized minority state-owned firms more than majority state-owned firms' R&D, likely as a tactic to have greater influence over their decision-making. Philipp Boeing, "China's R&D Subsidies—Allocation and Effectiveness," *Center for European Economic Research Discussion Paper* 14–103, November 2014, 2, 9–10.

‡Unless noted otherwise, this section uses the following exchange rate throughout: $1 = RMB 7.06.

§China's Ministry of Industry and Information Technology regulates and plans industrial policy for much of China's manufacturing sector, telecommunications, and other sectors. "Industrial production and technology" includes R&D expenditure related to manufacturing; software publishing; computer programming, consultancy, and related activities; information service activities; telecommunications; and engineering activities, technical testing, and analysis. Eva Benages et al., "The 2018 PREDICT Dataset Methodology," *European Commission*, 2018, 173, 175, 179.

¶German partnerships range from well-established companies expanding operations in China to startups forming strategic partnerships to access China's consumer market. For instance, German chemical makers BASF and Henkel announced plans in 2016 and 2017, respectively, to expand operations in Shanghai focusing on new materials used in automobile manufacturing, while German fiber startup Compositence GmbH launched a partnership with Chinese fiber startup GON Technology, based in the eastern port city of Qingdao, in 2017. South Korean firms have similarly launched facilities in China in exchange for market access, such as LG Chem's partnership with Geely in electric vehicle batteries. Nonetheless, both German and South Korea firms have expressed concerns about technology transfer to China. For instance, in 2018 a South Korean Court indicted nine Chinese individuals associated with Samsung's Chinese supplier Toptec Co., Ltd for leaking bendable display technology developed by Samsung. The stolen technology included a special lamination technique that took Samsung six years and $13.4 million to develop. *Reuters*, "South Korea's LG Chem to Team up with China's Geely on EV Batteries," June 12, 2019; *Reuters*, "South Korea Indicts Group for Leaking Samsung Display Tech to Chinese Firm," November 29, 2018; Li Dandan, "This Chinese Professor Filled the Domestic Carbon Fiber Gaps for [Military Helicopter Models] Z-10 and A-19 (中国这位教授填补碳纤维国内空白用于制造直10直19)," *Aviation Manufacturing Technology*, July 11, 2018. Translation; Jean-François Tremblay, "For Chemical Makers, R&D in China Makes Sense," *Chemical and Engineering News*, February 19, 2018; *Composites World*, "Chinese Firm Invests in Advanced Preforming Technology," August 28, 2017.

The United States is vulnerable from lack of alternate sources for minerals and other naturally occurring materials that could become vital to synthesizing important new materials. In 2017, President Donald Trump issued an Executive Order requiring the Department of the Interior, in coordination with several other executive agencies, to establish a strategy for reducing U.S. reliance on critical minerals, as well as improving domestic exploration and licensing and accessing materials through alternative sources, such as recycling.[129] In implementing the Executive Order, the Department of the Interior's June 2019 assessment found the United States relies on imports for more than 50 percent of supply for 31 of 35 minerals critical to U.S. manufacturing.[130] According to U.S. Geological Survey data, China accounted for more than half of global production for 13 of these minerals in 2017.[*] [131] Currently, North America produces less than 5 percent of the world's graphite and China produces 70 percent; exfoliating graphite is the primary method of synthesizing graphene.[132] If graphene becomes essential in any of the many potential applications currently being developed, such as quantum computing chips, China may be positioned to develop components much less expensively than the United States.[133]

U.S. Mineral Dependency and Supply Chain Control

China dominates global supply of numerous critical minerals and metals used in energy storage and other advanced technologies, creating supply risks for materials, components, and end products sourced from China. The Chinese government's approach to establishing dominance in global supply chains has been systematic, requiring coordination between industrial policy, domestic geological exploration, and commercial engagement in resource-rich developing countries, all supported by substantial state funding.

Chinese firms have built up economies of scale in extracting, separating, and processing critical materials, steadily increasing market share at the expense of other producers. In their natural form, many critical materials are mixed with other ores and minerals, some of which are radioactive, like thorium. Isolating these materials can be a highly polluting process that requires expensive technology to safely contain toxic byproducts, but China has enabled its domestic processing industry to undercut established international competitors by ignoring environmental costs and labor standards.[134] Chinese mining companies have also secured access to critical materials outside of China's borders, such as cobalt and lithium.[135] This ready supply of processed materials makes China a global price setter, and grants Chinese components manufacturers—the midstream segment of the supply chain—cheap and abundant access to these materials.[136]

*These 13 minerals are: aluminum, for which China produced 54 percent of the global total in 2017; antimony (72 percent); arsenic (69 percent); bismuth (80 percent of refinery production, rather than mine production); fluorspar (62 percent); gallium (94 percent); germanium (56 percent, excluding U.S. production); graphite (70 percent); magnesium metal (89 percent); rare earths (80 percent); tellurium (62 percent); tungsten (82 percent); and vanadium (56 percent). U.S. Department of the Interior and U.S. Geological Survey, *Mineral Commodity Summaries 2019*, February 2019, 21, 23, 25, 35, 61, 63, 69, 73, 103, 133, 167, 179, 181. Richard Silberglitt et al., "Critical Materials: Present Danger to U.S. Manufacturing," *RAND Corporation*, 2013, xii, 3.

Military-Civil Fusion and New and Advanced Materials

Efforts to leverage advances in Chinese commercial materials production toward military applications have a decades-long history and focus especially on catching up in materials used in aviation. For example, in implementing the 863 Plan, Chinese firms had for years struggled to produce high-grade carbon fibers used in military applications because of their lightness and strength. In 2005, an 863 Plan review committee approved Chinese fishing tackle maker Weihai Guangwei to develop carbon fiber for the military; today it is one of the PLA's largest suppliers of high-grade carbon fiber, and is credited with ending China's dependence on foreign sources.[137]

At the same time as China's military is closing the gap for high-performance materials used in aviation, it is also investing in emerging applications of new materials that may give its weapons systems an advantage over the United States. China has reportedly succeeded in using metamaterials to reduce the detectability of its military aircraft by radar.[138] Furthermore, China's patenting in metamaterials is highly concentrated in areas with dual-use potential, like antennae, suggesting a research focus on potential military advances. 41 percent of Chinese metamaterials patents through 2017 are in antennae versus 19 percent for the United States.[139]

Energy Storage

China has pursued advances in harnessing and storing renewable energy sources (e.g., hydropower, solar, and wind energy), as well as development of nuclear power to reduce its dependence of fossil fuels (both for environmental and strategic reasons) and to build capacity in clean energy technology.[140] Environmental objectives were initially secondary to these goals, and economic planners encouraged the development of "green technology" as part of China's overall industrial growth—China's solar technology was developed almost purely for export, rather than domestic use.[141] Through heavy subsidization and both licit and illicit technology transfers, China emerged as a testbed for applying innovations in renewables technology.[142] It has established itself as a leading exporter in solar panels and wind energy, displacing market incumbents like Danish turbine manufacturer Vestas and General Electric.[143] China's concept of green technology extends to all non-fossil fuel sources, and the acquisition of foreign technologies and push to increase installed capacity of clean energy also helped it develop a strong domestic supply chain in nuclear reactor components.[144]

Though Chinese firms succeeded in becoming globally dominant in wind and solar, industrial policies emphasizing top-down pursuit of quantitative targets led to substantial wasted investment and created overcapacity.[145] Part of China's success is owed to dumping this excess capacity on world markets, which drove down prices to the point that higher quality and more innovative products developed by U.S. firms were no longer competitive.[146] An investigation concluded in December 2014 by the U.S. Department of Commerce found that Chinese solar panels and panel components exported to the United States sold at between 21 and 62 percent below fair market price.[147] Though the United State imposed antidumping and countervailing duties in response, a 2018 follow up Section 201

Investigation by the Office of the U.S. Trade Representative found Chinese manufacturers evaded duties by locating production in other countries, prompting a 60 percent drop in price and 500 percent surge in imports that effectively rendered domestic U.S. production nonviable by 2017.[148] Currently, China is repeating many of the same industrial policies in growing its lithium-ion battery production capacity to serve its ambitions to become the leading new energy vehicle manufacturer.[149]

China's Policy Objectives and Current Capabilities in Energy Storage

China's production capabilities in lithium-ion batteries grew out of the government's concerted effort to dominate new energy vehicle production, as China has yet to indigenously develop internal combustion autos that compete with foreign producers.[150] After new energy vehicles were selected as one of seven Strategic Emerging Industries by state planners in 2010, China's provincial and local governments quickly built up local battery production. However, without consistent standards for batteries and charging stations, this resulted in overcapacity and a fragmented national market.[151] This accelerated investment in production capacity occurred with comparatively little investment in technology, locking factories into producing current lithium-ion technology, even if alternative forms prove more viable. Nonetheless, the market impact is clear: China increased global lithium-ion battery exports from $4.8 billion in 2013 to $8.0 billion in 2017.[152]

Since 2016, the Chinese government has focused on consolidating the industry, implementing consistent standards across provinces and building a handful of national champions, including Shenzhen-based BYD, the world's largest manufacturer of cellphone batteries, and Contemporary Amperex Technology Co., Ltd., now the world's largest manufacturer of lithium-ion batteries.[153] In 2018, China accounted for 61 percent of global lithium-ion battery production capacity, according to the Paulson Institute.[154] The United States accounted for less than 10 percent, almost all of which was attributable to Tesla's Gigafactory* in Nevada.[155]

Bloomberg Energy estimates China's total planned production of batteries would grow from 86.8 to 217.2 gigawatt hours (GWh) annually.[156] The national champions' plans focus on expansion of mega factories comparable to the Gigafactory, which would introduce scale economies that bring down the price per unit.[157]

U.S.-China Competition in Energy Storage

The United States has lost many of its major battery manufacturers, including several to Chinese acquisitions.† Since 2015, the Unit-

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*Tesla claims its factory is the world's largest, currently producing 20 GWh per annum, with plans to expand to 35. Kirsten Korosec, "Tesla, Panasonic Modify Expansion Plans for Gigafactory," *TechCrunch*, April 11, 2019; Damien Ma and Neil Thomas, "China Is Building the Batteries of the Future," *Foreign Policy*, April 2, 2019.

†Prominent examples include Massachusetts Institute of Technology spinoff A123 Systems and Aquion Technologies, both of which were acquired for low valuations after declaring bankruptcy. Chinese car parts maker Wanxiang Group acquired A123 Systems' automotive-battery unit, which accounted for the vast majority of the company, in 2012 for $256.6 million, only three years after the firm received a $249 million grant from the Department of Energy. In 2017 a subsidiary of China Titans Energy Technology Group acquired long duration energy storage firm Aquion for $9.2 million, a small fraction of the $190 million it had raised in VC funding. Christian Roselund,

ed States has sourced around 50 percent of imported lithium-ion batteries from China.[158] In 2018, the United States imported $1.5 billion worth of lithium-ion batteries from China, accounting for 47 percent of total imports, and 36 percent more than the $1.1 billion it produced domestically.[159] Imports from China also total more than imports from the United States' next biggest suppliers, Japan ($520 million) and South Korea ($744 million), combined.[160] Moreover, while Panasonic and LG Chem are still major players in rechargeable battery production, China's planned mega factories may lift it ahead of competitors, further increasingly global dependency on China.[161] Batteries are heavy and expensive to ship, so China will likely use its strong market position to establish or acquire production facilities close to automakers in other countries.[162]

In addition to accounting for 61 percent of global production, China also has substantial control of the supply chains for materials used in lithium-ion battery production. Upstream, it produces 77 percent of refined cobalt globally, a 10 percent increase in market share from 2012, and it produced 70 percent of the world's graphite in 2018.[163] Midstream, China accounts for a significant portion of the four main components used in assembling batteries: 45 percent of separators, 66 percent of anodes, 39 percent of cathodes, and 64 percent of electrolytes.[164]

Military-Civil Fusion and Energy Storage

China's expanded capacity in new energy vehicle batteries will likely have spillover benefits in other applications that require lightweight batteries and batteries with increased storage capacity. Both these features could change military dynamics by increasing China's ability to project force without refueling.[165] Currently, China is reportedly developing lithium-ion batteries to power air-independent propulsion submarines, which can last underwater much longer than conventional diesel-powered submarines.[166] Advanced batteries can also be used to power unmanned aerial vehicles (UAVs) with strike capabilities or reconnaissance drones.[167]

Aside from converting civilian capabilities to military use and vice-versa, military-civil fusion aims to strengthen the economic health of China's defense sector. Battery and fuel cell manufacturer China Shipbuilding Industry Group Power Co. is a textbook example: the Mao-era company was established to supply the PLA Navy and, after a series of state-directed mergers, it derives 20 percent of its revenue from defense sales, 20 percent from commercial marine products, and another 60 percent from other civilian products, such as supplying Mercedes, Audi, and BMW's conventional automobiles with batteries in the Chinese market.[168] The restructured state-owned enterprise is being showcased as an example of revitalizing China's defense industrial base through economic reforms.[169] At the same time, China Shipbuilding Industry Group Power Co. continues to pursue dual-use markets, such as nuclear marine propulsion and fuel cells.[170]

"China Titans Swoops up Aquion for $9.2 Million," *PV Magazine*, July 26, 2017; Patrick Fitzgerald, "Chinese Firm Wins Auction for U.S.-Backed Battery Maker," *Wall Street Journal*, December 9, 2012; A123, "Our Story, Leadership, and Locations – Overview."

Civil Nuclear Power

In addition to transport and digital infrastructure projects, China has used BRI to build future export markets for its nuclear reactors and raise its international profile. At present, China has only exported its indigenously developed Hualong One reactor to Pakistan and is negotiating construction of a reactor in Argentina.[171] However, it has signed agreements to establish future cooperation with several sub-Saharan African countries, including Kenya, Sudan, and Uganda.[172] These agreements either explicitly involve China exporting its Hualong One reactor, or lay the groundwork for China to become a major exporter of components and services like waste disposal and personnel training.[173] China General Nuclear Power Group (CGN) has also submitted a proposal to build a small plant in Namibia, where it also owns and operates the world's second-largest uranium mine.[174] China has also formed partnerships with advanced economies to gain know-how and increase its credibility as an exporter, most notably CGN partnering with Électricité de France to finance the Hinkley C Reactor in the UK.[*][175]

Influence in Fourth Generation of Reactors

Chinese nuclear companies are also keen to gain a foothold in the fourth generation of nuclear reactors,[†] and have sought out partnerships to develop advanced reactors and gain influence in international steering bodies.[176] Seattle-based reactor designer TerraPower was developing an advanced reactor with China National Nuclear Corporation, but shelved the project in response to October 2018 regulations from the U.S. Department of Energy on nuclear technology transfers to China. China National Nuclear Corporation is also developing two advanced reactors with CANDU, a subsidiary of the Canadian engineering firm SNC-Lavalin.[177]

A latecomer to the Generation-IV International Forum, an international body working to identify six types of reactors for the next generation of nuclear technology, China is trying to increase its influence through investing heavily in domestic trials of the reactors under consideration.[178] Lower demonstration costs from Chinese nuclear power firms' readiness to fund R&D and China's robust domestic supply chain for reactor components make it an attractive destination to test new reactor designs.[179]

U.S.-China Competition in Nuclear Power

Historically, the United States was a leading exporter of nuclear power technologies and exercised a dominant role in setting global nuclear governance norms through its own Nuclear Regulatory

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*The planned reactor at Hinkley Point C has been met with fierce pushback from within the UK due to high costs, questions over safety, and concerns about a Chinese company owning a 33 percent stake in critical infrastructure, as well as alarm over GCN's 2016 espionage indictment for attempting to steal U.S. nuclear technology. The U.S. Department of Commerce added CGN to the Entity List in August 2019, and the Department of Energy introduced a presumption of denial for exports to CGN in October 2018, citing concerns that civilian technology was being diverted to military use. Christian Shepherd, "US Blacklists Chinese Nuclear Company Over Theft of Military Tech," *Financial Times*, August 15, 2019; Holly Watt, "Hinkley Point: the 'Dreadful Deal' Behind the World's Most Expensive Power Plant," *Guardian*, December 21, 2017.

†The third generation of nuclear power included Westinghouse's AP-1000. The international body overseeing the third generation, the Multinational Design Evaluation Program, was launched by the U.S. Nuclear Regulatory Agency and France's Nuclear Safety Authority. *World Nuclear Association*, "Generation IV Nuclear Reactors," April 2019.

Commission and multilateral bodies like the International Atomic Energy Agency.[180] While the United States retains leadership in advanced reactor design, the decline of the United States' reactor components production and lack of domestic demand make it likely that advanced reactor demonstration will occur in other markets.[181] Between decreased exports and low domestic appetite for R&D of advanced reactors, the United States is in danger of losing technological leadership and its influence in international rule setting for nuclear safety and security.[182] Additionally, because of the high costs of installation and long lifecycle of reactors, if the United States does not participate in the next wave of global reactor installation, it will likely be cut off from reentering lost markets for decades.[183]

Implications for the United States

U.S. technological leadership and the U.S. approach to innovation are under threat in areas that will likely underpin the next generation of technology advancement. At present, the United States retains leadership at the beginning and end of the supply chain for many advanced technologies, which tend to capture the most value.* It produces a substantial portion of foundational research that precipitates technological breakthroughs, and develops many of the most innovative components to advance niche applications, which often set the direction for and trickle down into mass market use. Despite these advantages, U.S. economic competitiveness and national security are at risk from China's far more aggressive efforts to translate basic research to commercial application, systematic approach to controlling supply chains, attempts to influence international standards setting, and other technology acquisition strategies.

Loss of U.S. production to China limits gains from innovation in manufacturing processes, while China's dominance of global supply chains for critical materials and components creates further risks to U.S. economic and national security.[184] Cheaper access to raw materials and components compounds market distortions from Chinese industrial overcapacity that undermine returns on innovation, deterring U.S. firms from developing more advanced technologies. In seeking to build an economic order that benefits Chinese firms, the Chinese government is also promoting its own version of standards and using commercial diplomacy to further its influence in international governance. The confluence of these threats is most acute in emerging technologies like AI, for which the Chinese government is pursuing a systematic plan to achieve economic and military superiority.

Valley of Death

While the U.S. government funds some basic research and offers incentives like the R&D tax credit to spur innovation, the Chinese government uses prescriptive and interventionist methods to build supply, generate demand, and guarantee a market for nascent in-

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*The founder of Taiwan electronics maker Acer, Stan Shih, described the profitability of each step of a global value chain as forming a "smiling curve," because upstream activities like R&D and downstream activities like marketing and aftersales service have the most value added, while manufacturing, in the middle, has the least value added. *United Nations Conference on Trade and Development*, "Tracing the Value Added in Global Value Chains: Product-Level Case Studies in China," 2015, 2.

dustries. China's approach helps new technologies overcome obstacles to commercialization, often referred to as "the valley of death."* For instance, China jump-started its new energy vehicle industry through heavy purchase subsidies offered only for domestic vehicles, top-down industry consolidation, and building out urban charging infrastructure.

Coupled with China's extensive domestic supply chains for components, similar policies lower the costs of innovation, incentivizing firms to prototype and demonstrate new technologies, like advanced nuclear reactors, in China. Due to this supportive policy environment, China is positioned to be a primary destination for research collaboration and to leverage its strong manufacturing capabilities to gain access to new markets. As China moves into new subdomains of AI such as AVs, it may be able to catch up to the United States or more successfully commercialize an inferior technology, due to its ability to prototype cheaply and rapidly and its willingness to provide policy support for emerging industries.

Spillover from advances in other technologies can present further risk to the United States. For example, China's existing advantages in commercial drone manufacturing will improve as Chinese battery manufacturers develop cheaper, lighter, and longer-lasting lithium-ion batteries. This positions China to dominate in production of UAVs for industrial and service applications like fertilizing drones or delivering drones, even if the United States has more sophisticated AI to drive UAVs.

Home Alone Effect

Once the critical parts of the U.S. manufacturing ecosystem move overseas, it is difficult to maintain leadership at the high end of the value chain because the United States will no longer benefit from innovation that happens on the shop floor. For instance, most of the advances enabling China to become a leader in lithium-ion battery production are improvements in the manufacturing process, rather than advances in the underlying technology. In fact, the foundations of China's lithium-ion battery industry stem partially from acquisitions of U.S. companies that struggled to maintain profitability in the United States.

China's efforts to localize supply chains deepen this trend. For example, ChemChina's acquisition of German machine tooling firm KraussMaffei will help China improve its engineering of composite materials and reduce dependence on foreign providers. Loss of leadership in commercializing materials research would leave major U.S. export industries like aerospace and automotive especially vulnerable to competition, both from the loss of a key export market in China and with Chinese firms in third country markets.

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*The "valley of death" refers to the period when basic research has established the potential viability of a new technology, but lack of funding to take the technology from the laboratory to early stages of commercialization prevents further development of that technology. Timothy M. Persons et al., "Nanomanufacturing: Emergence and Implications for U.S. Competitiveness, the Environment, and Human Health," *U.S. Government Accountability Office*, GAO-14-181SP, January 2014, 25–27.

China's Growing Influence in International Standards Setting

Influencing global standards-setting bodies in favor of Chinese firms and priorities is a key part of China's technonationalist strategy. The 2018 revision of China's Standardization Law includes provisions aiming to strengthen the role of Chinese standards in international bodies and promote Chinese standards through BRI.[185] Establishing influence in the global standards-making process is central to China's plans to become a world leader in AI. Similarly, China's nuclear power development focuses on hosting prototypes for the next generation of reactors and positioning itself to become a leading exporter, both of which would allow it increased say in multilateral governance organizations. Chinese institutions are also expanding their participation in international standards-making bodies like the Institute of Electrical and Electronics Engineers and International Standards Organization, and may wield their influence to develop standards that favor Chinese technologies foundational to developing AI subdomains.[186]

China's government has been especially active in international standards setting for technologies that will support application of AI, such as the Internet of Things and 5G, aggressively seeking to place Chinese nationals or companies in leadership positions within the International Telecommunication Union and other bodies focused on connected technologies and coordinating between firms to ensure their participation in international processes is unified.[187] These efforts could undermine the United States' ability to set international norms for the application of sensitive technologies and control their proliferation. In conjunction with commercial diplomacy aimed at fostering export markets and science and technology collaboration through BRI, Chinese standards-making bodies could wield expanded international influence to promote alternative technology standards that exclude U.S. firms.

Strategic Threat from Military-Civil Fusion

China's military-civil fusion effort to make the military and civilian sectors mutually supportive poses a range of threats to U.S. national security and economic competitiveness. Increased collaboration between China's military and civilian sectors and the PLA's adoption of next-generation systems stand in contrast to the United States' dependence on legacy platforms and weapons.[188] As commercial, rather than military, applications increasingly define the technological frontier, the United States is at risk that advances in AI, new materials, and new energy provide absolute or asymmetric advantages in warfare. Although China's current capabilities do not appear to indicate any immediate substantial threat, the intent of China's industrial policy and military strategy is clear.

China's broad-based efforts to harness civilian technology for military use have focused especially on AVs, including unmanned vessels and drones. For example, Chinese firms and research institutions have achieved some drone swarm capabilities that surpass the United States.* Militarized application of commercial AI developments

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*Drones swarms use AI to provide an asymmetric advantage against high-value targets like aircraft carriers or submarines, as drones are cheap to produce and maintain, and have high survivability in swarms. Chinese aerospace research firm China Electric Technology Corporation could also enable greater autonomy in other advanced weapons systems, such as hypersonic glide missiles, and allow the PLA to deploy intelligent logistics and virtual reality combat simulations.[189] Facial recognition, voice recognition, and other biometric data analysis are key enabling technologies within China's surveillance state, and in the future the PLA may leverage big data and AI to enhance propaganda and psychological operations.[190]

On a national scale, the sheer breadth of China's technology demonstration platforms and local initiatives under the umbrella of military-civil fusion allows the PLA to identify which civilian enterprises or research institutes have produced the most promising technologies for militarization. The extensive and opaque network of connections between civilian entities and China' military sharply increases the risk that U.S. universities and corporations become partners in military-civil fusion, as research and collaboration ostensibly conducted by the civilian sector can be made freely deployable by China's military.[191] The decades-long pattern of Chinese research partnerships, acquisitions, and economic espionage focused on sensitive technologies makes clear that obtaining scientific knowledge to close gaps in military capabilities is an unwavering priority, and the influence of military institutions extends far into China's civilian sector.

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also holds the record for largest fixed-wing aerial drone swarm, at 119. Unmanned vessel manufacturer Yunzhou Tech has reportedly tested underwater "shark swarms." U.S.-China Economic and Security Review Commission, *Hearing on Technology, Trade, and Military-Civil Fusion*, written testimony of Elsa Kania, June 7, 2019, 25; Elsa Kania, "Swarms at War: Chinese Advances in Swarm Intelligence," *China Brief* 17: 9, July 6, 2017.

Addendum I: China's Development of AI Technologies

AI Technology	Applications	Key Industrial Policies	China's Current Capabilities	Key Companies
Machine Learning, which includes Deep Learning	Foundational for other areas of AI	Cultivating talent in advanced machine learning and leading in machine learning theory are cornerstones of China's Strategy to dominate in global AI by 2030, unveiled in 2017. The National Development and Reform Commission has also tapped search engine giant Baidu to lead a nationwide online deep learning lab in coordination with Tsinghua and Beihang universities.	Chinese researchers have closed the gap with the United States in publication volume, but China lacks talent in the top echelon. Engineers focus mostly on commercial gains, not fundamental breakthroughs. China's advantages in sheer volume of data are curtailed by its ability to label and analyze this data. China also lags in producing chips optimized for machine learning.	General: Alibaba, Tencent, Baidu; Chips: Cambricon (used in Huawei phones), Horizon Robotics
Natural Language Processing (NLP)	Speech/voice recognition, translation, information retrieval/extraction, query answering, sentiment analysis	NLP is listed as one of eight "key common technologies" to be developed in China's AI strategy. Chinese universities are partnering with companies to develop NLP applications, and several Chinese industry associations have launched respected conferences.	In research, China has been second behind the United States for five years. In industry, China is leading in chatbots and is developing machine translation for Chinese to languages in BRI countries. iFlytek is a leader in speech recognition for spoken Chinese.	Baidu, iFlytek; Microsoft Research Asia is a major player for machine translation and chatbots.
Computer Vision and Biometrics	Facial and other image recognition, machine vision (analyzing images for inspection and process control)	China's smart cities initiative promotes surveillance technology, and many companies have contracts with public security bureaus. Computer vision accounted for 35 percent of China's AI market in 2017.	Numerous facial recognition companies, including many startups, are powering China's surveillance state. In turn, internet giants like Huawei are integrating this tech into—and exporting—"Safe City" systems.	SenseTime, Yitu, Megvii (Face++), Xloong, Zoloz, DeepGlint, Huawei

Addendum I: China's Development of AI Technologies—*Continued*

AI Technology	Applications	Key Industrial Policies	China's Current Capabilities	Key Companies
Robotics	Industrial robots, commercial service robots, and personal service robots	China's Intelligent Manufacturing Plan, a supplement to Made in China 2025, called for extensive investment in industrial robots; numerous provincial funds have been set up to upgrade China's manufacturing capabilities.	China's domestic sales of industrial robots have increased significantly, but it remains heavily dependent on the United States, Europe, and Japan for robotics components. It has formed joint ventures with several EU-based firms.	Siasun, GSK CNC Equipment, Effort, Estun, Wuhan Huazhong
AVs and other Unmanned Autonomous Systems	Passenger vehicles, delivery vehicles, UAVs like drones	AVs: China legalized AV testing in 2017 and launched a national strategy in December 2018 emphasizing research funding and special test zones. It may also pursue protectionist measures. Drones: Policy supports developing industrial application (e.g., in agriculture).	AVs: China is three to five years behind global leadership in algorithms that enable successful driving, but likely to catch up. It is farther behind in sensors, computing platforms, and systems integration. Drones: DJI controls 70 percent of the global consumer market.	AVs: Baidu, Pony.AI, SAIC; Drones: China Electronics Technology Group Corporation, DJI

Note: Other notable applications of AR technologies include virtual and augmented reality, healthcare, and finance. Underlying these applications are chips optimized for AI and sensors.
Source: Various.[192]

Addendum II: Select New Materials and Applications

New Material Category	Applications
Metamaterials: Artificial composites with electromagnetic properties that do not occur in natural materials, such as the ability to absorb rather than reflect light or view microscopic phenomena with fidelity not possible from natural lenses.	China's stealth aircraft uses metamaterials, likely to enhance its antennas and jamming capabilities, and China is also reportedly using metamaterials to experiment with changing how its nonstealth fighters appear on radar. Nonmilitary uses of metamaterials may someday include superlenses used to observe viruses or DNA.
Nanomaterials: Materials with an external dimension or internal structure on a nanoscale (less than 100 nanometers), generally refined from naturally occurring materials. Well-known examples include graphene and carbon nanotubes.	Current mass market applications include filtration, textiles, cosmetics, environmental protection, and food packaging. Many more potential applications are in development. Graphene lens, a single atomic layer of carbon atoms, is especially useful in electronic applications due to its high conductivity, as well as in touchscreens or for other optical applications due to its transparency. Small amounts of graphene oxide, a powder of graphene crystals, can be mixed into many materials to increase their strength or absorption.
Electrical Materials: Organic semiconductors, polymer-based electronics, and materials used in quantum computation, high-density energy storage, and low power displays.	Fabrication of quantum computers and other advances in electronic computing can break through the storage and speed limitations of silicon semiconductors. Researchers are pursuing manipulation of carbon nanotubes, exploitation of flaws in conventional semiconductors, or materials that send signals via trapped ions or manipulation of light particles (photonics).
Biomaterials: Any material engineered to interact with a living system, either for a therapeutic function (e.g., tissue regeneration, treating an illness), or to monitor a system and inform diagnosis.	For treatment, application of nanomaterials to replacement and transplant surgery has enabled 3D printing of implants to integrate with the body's systems, and highly conductive biomaterials have also been used to reconnect severed nerves. For diagnosis, biosensors like neural implants can gather medical data to tailor treatment to individual patients or model medical experiments computationally with AI.

Note: Electrical and Biomaterials are categories unified by application, rather than chemical composition, and may include nanomaterials. Graphene, for instance, has extensive electronic applications, some of which also have medical applications.

Source: Various.[193]

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