

PART III

COMPETITION IN CONTESTED FRONTIERS

CHAPTER 6: INTERLOCKING INNOVATION FLYWHEELS: CHINA'S MANUFACTURING AND INNOVATION ENGINE

Executive Summary

In the decade since launching Made in China 2025 (MIC2025), the Chinese Communist Party's (CCP) industrial, science, and innovation policies have multiplied and expanded in scope. China deploys an arsenal of tools to execute these policies and affect its capacity to develop and produce advanced technology. The evidence shows that comprehensive strategic planning, massive state funding, and adaptive implementation have allowed China to overcome previous industrial policy failures. As roads and bridges act as public goods benefiting the entire state, China's policies have constructed an "industrial commons"—a collective resource base Chinese firms can exploit to advance technological capabilities. This industrial commons positions China to develop and support firms that will dominate established markets and control emerging sectors.

Numerous industrial policy successes demonstrate the strength of China's industrial commons and how advances in overlapping industries catalyzed innovation in other technologies or products. China's electric vehicle (EV) industry was built on a range of preexisting capabilities, including lithium batteries for consumer electronics and a large automobile manufacturing sector. In turn, EVs served as a platform that helped drive innovation in directly related sectors, like battery technology, and in related capabilities, like LiDAR used in autonomous systems. Similarly, China's capabilities in industrial robotics are supporting the emergence of artificial intelligence (AI)-enabled factory production models, promising scalable gains across the manufacturing sector. In synthetic biology, China's sophisticated laboratory infrastructure and growing biotech manufacturing base are positioning it to become a leader in commercializing global scientific discoveries from pharmaceutical to non-pharmaceutical applications, with state-backed facilities enabling rapid translation from research to production at scale.

Key Findings

- Chinese industrial policy has established the landscape for becoming an advanced manufacturing and innovation powerhouse. By conducting industrial policy on an unprecedented scale, China now leads global innovation in many targeted sectors and has built a manufacturing base that is integrated into many legacy and advanced technology supply chains.
- China's industrial policy systematically constructs clusters of interconnected manufacturing capabilities while securing control over foundational technologies. Innovation follows manufacturing, and China is leveraging this approach to generate "interlocking innovation flywheels"—technical advances in one sector rapidly catalyze breakthroughs in adjacent sectors, creating compounding technological advantages that accelerate with each cycle.
- Through MIC2025 and related policies, China has secured dominance in much of the legacy and advanced componentry for today's most prevalent consumer and enterprise technology products. Given that key innovations often happen on the factory floor, China's current dominance gives it a significant leg up in terms of future cycles of iteration and innovation as well as a source of essential components for new technologies.
- China's industrial policy and Party-state control have also positioned it to attain first-mover advantage in technologies of the future, like synthetic biology, quantum technologies, and automation (including humanoid robots). Where the key sectors in MIC2025 mostly reflect mature markets in which China seeks to displace incumbents, becoming the first mover in emerging and nascent technologies would position China to set the future rules of the road.
- Rapid growth in targeted industries has not offset weakness in the broader economy, producing a two-speed economy in which prioritized high-tech sectors contrast with lagging sectors beset by structural economic challenges. All indications suggest General Secretary of the CCP Xi Jinping will prioritize China's technology ambitions over other policy goals. He believes developing and moving into new technologies can strengthen China's competitiveness vis-à-vis the United States and other prospective competitors. China's expenditure on industrial policy has had a cumulative impact that will continue to drive advances in research and development (R&D) and manufacturing capabilities, meaning that momentum in the high-speed economy will likely continue to grow.
- Overinvestment and overcapacity resulting from China's industrial policies have consistently led to large economic distortions across the value chain for targeted sectors. These distortions often threaten U.S. producers and developing economies attempting to move up the value chain. They also

create an environment of intense competition within China as firms compete for market share in artificially expanded markets, forcing firms to increase efficiency, reduce production costs, and repeatedly cut sales prices to stay ahead of rivals. The firms that survive this process, like EV maker BYD, are then typically highly competitive in global markets.

- In the early stages of these product cycles, and often beyond, China's approach is divorced from market principles, and its success largely stems from using subsidies, state coordination, and other nonmarket practices to undercut competitors in foreign markets.

Introduction

China was already the world's largest manufacturer when it unveiled MIC2025 and laid out precise market share and localization targets aimed at catching up with and surpassing incumbents in ten key sectors, ranging from aerospace equipment to biopharmaceuticals and advanced medical devices. While China has successfully reached many of its MIC2025 targets, the important questions for policymakers look forward, not backward: What industries will China seek to dominate next? How will it apply the lessons learned from MIC2025 toward its next set of technology development goals?*

To answer these questions, this chapter maps China's vast industrial policy toolkit, detailing both the CCP's strategic approaches and specific tactics to foster successful firms. It then uses case studies to show how the cumulative and mutually reinforcing gains from industrial policy have fostered the world's most advanced industrial commons—the shared pool of resources and capabilities that drive innovation and technological upgrading. Case studies illustrate this dynamic:

- In autonomous systems and robotics, China's robust manufacturing ecosystem positions it to make advances through mutually reinforcing improvements in adjacent technologies.
- In synthetic biology, China's sophisticated laboratory infrastructure and growing biotech manufacturing base are positioning it to become a leader in commercializing global scientific discoveries from pharmaceutical to non-pharmaceutical applications, with state-backed facilities enabling rapid translation from research to production at scale.
- In quantum information sciences, concentration of talent and resources in laboratories—combined with advanced manufacturing capabilities—is positioning China to scale quantum technologies from research breakthroughs to commercial deployment, as discussed in detail in the Commission's paper on U.S.-China competition in quantum technologies.

While Congress long ago provided the Executive Branch with broad industrial policy authorities, and U.S. policy mechanisms ex-

*This chapter draws on the Commission's 2025 hearing on "Made in China 2025—Who Is Winning?," consultations with policy experts, and open source research and analysis.

ist—or are under development—to address individual facets of this multipronged issue, this challenge cuts across every department, agency, and border. The United States currently lacks any coherent plan—no empowered official and no strategy to bend the innovation curve in critical technologies to ensure continued U.S. leadership, rebuild our R&D capabilities, and break our dangerous and growing dependence on Chinese supply chains.

MIC2025 and Contextualizing China's Industrial Drive

This chapter uses “MIC2025” and “the MIC2025 period” as shorthand to refer to China's evolving industrial policy approach from 2015 to 2025. China launched its MIC2025 program in 2015 with the goals of becoming an advanced “manufacturing powerhouse” and establishing China as a global leader in ten technology sectors.*¹ MIC2025 itself was not unique in the objectives it set to achieve or the sectors it identified as important but rather in combining these sectors into a grand strategy to make China a manufacturing superpower.² China's Innovation-Driven Development Strategy, an overarching plan to guide Chinese innovation released by the CCP Central Committee and the State Council shortly after MIC2025, espoused a broader vision that aimed to reorient China's technological approach and strengthen its capacity for innovation.³ Additionally, as detailed below, China's government subsequently issued a series of policies that sought to develop industries beyond the original scope of MIC2025, such as AI and synthetic biology, while employing many of the same approaches.⁴

China's Whole-of-Nation Drive toward Industrial Policy

Since launching a sweeping initiative to improve China's capacity for local innovation in 2006, China's leaders have introduced a relentless array of industrial, science, and technology policies in hopes of overtaking, displacing, and ultimately leapfrogging advanced economies in emerging fields.⁵ The focus on catching up to and surpassing the United States and other industrialized nations took on greater urgency during the MIC2025 period, as Xi Jinping described the ongoing technological revolution as the “main battlefield of international competition.”⁶ Much as the United States attained decades of technological leadership by capitalizing on breakthroughs in information and communications technologies following World War II, Chinese leaders assess that technological advances are key to overtaking the United States. In addition to providing geopolit-

*MIC2025 aimed to move China up the global value chain and establish manufacturing dominance by targeting state support in ten sectors that Beijing considered strategically important yet underdeveloped. These were next-gen information technology and semiconductors, computer numerically controlled machines and robotics, aerospace, offshore engineering equipment and high-tech ships, advanced rail transportation equipment, energy-saving and new energy vehicles, electrical equipment, agricultural machinery and equipment, new materials, and biopharma and high-performance medical devices. For an evaluation of China's performance toward its MIC2025 goals, see Daniel Blaugher, Benton Gordon, and Matthew Dagher-Margosian, “Made in China 2025: Evaluating China's Performance,” *U.S.-China Economic and Security Review Commission*, November 2025.

ical advantage, the CCP believes capitalizing on the current technological revolution will enable it to overcome perceived existential threats to China's economic growth and resilience, national security, and social stability as well as its legitimacy and control, including:

- *Expanding China's share of value added in global value chains:* Despite becoming a major manufacturing center by the early 2000s, China's production was initially trapped in assembly for export—often the lowest rung on the value chain. Chinese manufacturers have gained a larger share of value added, as China has shifted from net reliance on foreign components like LCD displays to being a major exporter.⁷ Chinese-owned factories also account for a much larger share of exports than those with foreign ownership, whose share of China's exports plummeted from 46 percent in 2014 to 27 percent in 2024.⁸ Nonetheless, more complex activities like the product design and production of niche, high-end components are still largely located in the United States and other advanced economies.⁹
- *Reliance on foreign chokepoint technologies and vulnerability to economic coercion:* Reducing and eventually eliminating reliance on foreign technology is now Beijing's top technology priority, driven by heightened U.S.-China tensions and expanded U.S. export controls.^{*10} China's 14th Five-Year Plan (2021–2025) explicitly identified technology self-reliance and overcoming bottlenecks as key goals, and these objectives form part of a broader effort to ensure the economy is prepared for “extreme situations,” including protracted war.^{†11} Concurrently, the CCP is deepening its ability to weaponize foreign dependence on Chinese production. In a 2020 speech, Xi stated, “We must tighten international production chains’ dependence on China, forming a powerful countermeasure and deterrent capability against foreigners who would artificially cut off supply.”¹²
- *Barriers to innovation in China's defense industrial base:* Stove-piped bureaucracy and weak market incentives among China's state-owned defense conglomerates have long hampered China's defense research, development, and acquisition (RDA) processes.^{‡13} Among other goals, China's Military-Civil Fusion (MCF) strategy seeks to remedy this shortcoming by leveraging commercial innovation and civilian technical expertise for military applications.¹⁴ MIC2025 and other industrial policies aim to align China's manufacturing ecosystem with the needs of its defense industrial base.¹⁵

*Union College political scientist Mark Dallas highlighted four inflection points in China's pursuit of technological self-reliance: in 2014, following revelations about U.S. covert digital surveillance capabilities revealed in documents leaked by Edward Snowden; in 2018, following the United States' introduction of export controls on China's telecommunications champion ZTE over its role in evading Iran sanctions; controls on Huawei in 2019; and the broadening of advanced chip controls to cover all of China in October 2022. Mark Dallas, written testimony for the U.S.-China Economic and Security Review Commission, *Hearing on U.S.-China Competition in Global Supply Chains*, June 9, 2022, 17.

†For more on China's efforts to prepare for extreme scenarios and its stockpiling measures, see U.S.-China Economic and Security Review Commission, “China's New Measures for Control, Mobilization, and Resilience,” in *2024 Annual Report to Congress*, November 2024, 458–539.

‡For more on China's drive for defense innovation, see U.S.-China Economic and Security Review Commission, “Weapons, Technology, and Export Controls,” in *2023 Annual Report to Congress*, November 2023, 439–452.

- *Looming demographic challenges threaten China's economic growth:* The size of China's population dropped for the first time in decades in 2022, and its workforce is projected to continue shrinking.*¹⁶ As such, China will rely on further increases in factory automation and replacing human labor with autonomous systems to mitigate the adverse effects of an aging and declining population, while advances in biomedicine will likely offer the potential to extend the working life of the population. In anticipation of these challenges, China has made robotics and related autonomous systems, as well as biopharma, top priorities since the early 2010s, including in MIC2025.¹⁷

Multi-Pronged Industrial Policy Strategy

To address these challenges, China is undertaking a whole-of-nation effort to lead global innovation and high-value manufacturing through industrial policy. Building on the approach launched with MIC2025, Beijing has increasingly organized its policies around the concept of the “new-style whole-of-nation system,” a strategy that takes inspiration from China's approach to accelerate its nuclear weapons efforts in the 1960s and 1970s.¹⁸ This approach seeks to mobilize all resources available to advance China's technological objectives. At a strategic level, China's approach adopts key features of successful industrial policies from other East Asian economies—particularly Japan and South Korea—but builds on them to attain a breadth and scale without historic precedent. At the operational level, China's implementation of industrial policy under Xi has been highly iterative, refining policies as goals are met, lessons are learned, and technology evolves. At a tactical level, China's national and local governments have developed an ever-expanding suite of incentives and programs to enlist the private sector in fulfilling state objectives as well as complex methods to acquire foreign technology. Each of the strategies and tactics detailed in this chapter are important in themselves, but the defining features of China's industrial policy are its scope and the degree to which its constituent parts are coordinated, driving what is initially an inefficient and often wasteful ecosystem into one that encourages fierce competition for government support and ultimately accelerates innovation.

Vertical Integration and Industrial Clusters

Like Japan and South Korea, China has moved up the value chain through scale economies generated by a vertically integrat-

*China has an unusually low official retirement age—currently set at 60 for men and 50–55 for women—which exacerbates the challenges of an aging population. China's restrictions on labor mobility and weak social safety net for migrant labor—often factory and low-skill service workers from inland provinces working in coastal cities—also mean its workforce is inefficiently deployed, adding to the challenge of slowing growth from an increasing dependency ratio. Conversely, reforms to these policies could mitigate the demographic drag—to a degree. Beginning in 2025, the government plans to gradually raise the retirement age to 63 for men and 55–58 for women by 2040, but demographers project the reform will only marginally boost the working population. Arthur Kroeber, “China's Slowing Economic Growth: Causes and Impacts,” in *China's Economic Slowdown and Its Impact on Trading Partners*, eds., Arthur Kroeber and Jonathon Marek (National Bureau of Asian Research, June 2025), 16–17; Joe Leahy and Wenjie Ding, “China to Raise Retirement Age for First Time since 1978,” *Financial Times*, September 13, 2024; Fan Zhai, “Macroeconomic Implications of China's Population Aging: A Dynamic OLG General Equilibrium Analysis,” *AMRO Working Paper*, September 2024, 21–22; Dudley L. Poston, “Raising the Retirement Age Won't Defuse China's Demographic Time Bomb—But Mass Immigration Might,” *The Conversation*, August 15, 2024; Alicia Garcia-Herrero, “China's Aging Problem Will Be Much More Serious When Urbanization Is Completed,” *China Leadership Monitor* 80 (Summer 2024).

ed production base.¹⁹ Chinese policymakers sought to emulate the success of conglomerates, like South Korea's chaebol (e.g., Samsung and SK Group) and Japan's keiretsu (e.g., Mitsubishi and Mitsui), that became leading exporters by mobilizing resources and reducing costs through integrating the entire supply chain within a tightly knit corporate network.²⁰ This approach focused on fostering national champions that could serve as architects of supply chains and translate central policy priorities into economic realities.²¹ Vertical integration also translated well to China's top-down economic management, enabling policymakers to implement decisions through centralized governance structures.

Additionally, Chinese policies concentrate support geographically through industrial clusters, seeking to collocate innovative firms and complementary production processes to promote knowledge spillovers and other agglomeration externalities. In implementing MIC2025, China selected 30 pilot cities to support industrial upgrading, technological innovation, and talent training.²² China's flagship industrial parks, National High-Tech Industrial Development Zones, have also grown significantly under MIC2025, from around 50 zones in 2009 to 173 by 2022.²³ These zones host 84 percent of China's State Key Labs, which are government-supported research organizations tasked with carrying out cutting-edge basic and applied research and building out China's capacity for indigenous innovation.²⁴ Additionally, Chinese conglomerates use "innovation consortia" to foster key breakthroughs by coordinating R&D efforts across firms and labs within a vertically integrated supply chain.²⁵ After codifying the concept in the 2021 Science and Technology Law, China counts hundreds of innovation consortia across various sectors, ranging from new materials to carbon capture and sequestration technology.²⁶ In 2024, China had 26 of the World Intellectual Property Organization's top 100 global science and technology clusters—the most of any country—and four of the global top ten.²⁷

Scale and Persistence

Rather than choosing a few sectors to build through industrial policy like Taiwan's approach to semiconductors, China has pursued state-led development across all its core manufacturing industries simultaneously.²⁸ Under MIC2025, China's industrial policies shifted focus from near-term export opportunities to fundamental improvements in China's manufacturing ecosystem and general-purpose technologies.*²⁹ Because of the breadth of industries it targeted, China was able to benefit and learn from intermittent victories even when many of its industrial policy results were mixed.† As China

*General-purpose technologies refer to transformational technological advances that create new growth engines and radically alter the trajectory of technological development. Examples of past general-purpose technologies include electricity, the steam engine, and computerization. Jeffrey Ding, *Technology and the Rise of Great Powers: How Diffusion Shapes Economic Competition* (Princeton University Press, 2024), 22–23.

†Such a recalibration appeared to occur in the middle of China's Medium- and Long-Term Plan for Science and Technology Development (2006–2020), which set the goals of China's innovation strategy to 2020 and laid the groundwork for the more prescriptive industrial policy documents that followed. By 2012, six years into the plan, China's leaders seemed to voice disappointment with progress toward the plan's objectives, and China's then-Vice Premier wrote, "Chinese capacity for indigenous innovation is weak, Chinese industrial technology is at a low level, and Chinese basic and cutting-edge research is unimpressive." A subsequent policy document proposed a shift in approach toward helping firms lead in innovation, breaking with the idea of government-driven "megaprojects" that were pursued under the Medium- and Long-Term Plan.

has moved to target additional sectors, the spillover benefits and network effects from prior rounds of industrial policy have helped firms gain a foothold in markets more quickly. For instance, leading EV maker BYD got its start as a cellphone battery manufacturer before shifting to lithium-ion batteries for vehicles.

Automation and Digitization as Long-Term Targets in MIC2025

Aside from the ten targeted sectors, MIC2025 encouraged widespread integration of automation, digitization, and AI integration (which China calls “intelligentization”)* across its manufacturing ecosystem in a bid to lead the “Fourth Industrial Revolution.”³⁰ This effort was closely linked with China’s Internet Plus strategy, first proposed by then Premier Li Keqiang in 2015, which aimed to digitize the economy and apply information technology solutions like cloud computing, big data, and the Internet of Things to industrial production.³¹ Among other objectives, the policy aimed to harness the transformative potential of digital technologies to create “smart factories”† throughout the manufacturing process.³²

Iterative Implementation and Policy Experimentation

Chinese industrial policies during the MIC2025 period built upon one another, continuously deepening government support and refining execution toward methods that delivered results. To implement MIC2025, China issued 445 national-level policy documents providing detailed guidance and implementing regulations, in addition to scores of provincial- and municipal-level policies.³³ Since 2015, China has also deployed numerous industrial policies targeting sectors beyond the ten prioritized under MIC2025, such as China’s National AI Development Plan, issued in 2017.³⁴ These reinforce and extend MIC2025. For instance, the AI Plan includes broad support for industrial automation and autonomous vehicles; this support builds on and benefits the same companies targeted by the robotics and new energy vehicle (NEV) policies under MIC2025.³⁵ The proliferation of planning across China’s bureaucratic hierarchy contributes to an adaptive policymaking process—one that is augmented by the discretion and flexibility local-level officials have in implementing top-level directives, although a recentralization of power under Xi has narrowed the scope for experimentation (see textbox).³⁶

Local-Level Experimentation Duplicates Efforts to Innovate across the Economy

Though leaders in Beijing set the science and industrial policy agenda, Chinese industrial policy is not implemented according to

Tai Ming Cheung et al., “Planning for Innovation: Understanding China’s Plans for Technological, Energy, Industrial, and Defense Development” (prepared for U.S.-China Economic and Security Review Commission), July 28, 2016, 34.

*The term intelligentization (智能化) is literally translated as “becoming intelligent” and is used in Chinese policy documents to refer to making systems capable of autonomous perception, learning, decision-making, and action. Xu Zongben, “把握新一代信息技术的聚焦点” [Grasping the Focal Points of New-Generation Information Technology], *People’s Daily*, March 1, 2019.

†Smart manufacturing refers to a production line where interconnected machines collect large volumes of data, communicate across the factory floor, and adaptively make decisions to optimize production. Smart factories promise a more flexible and customizable production process. Jost Wübbeke et al., “Made in China 2025: The Making of a High-Tech Superpower and Consequences for Industrial Countries,” *MERICs*, December 2016, 13.

a singular centrally devised plan. Instead, China's top-down target setting encourages local experimentation in policy approaches to pursue these objectives, with a recent detailed National Bureau of Economic Research working paper estimating that over 80 percent of China's industrial policies are issued by subnational governments.³⁷ These policies range from financial incentives to regulatory reforms, creating multiple innovation pathways that can accelerate tech development, though they often result—accidentally or by design—in excess production. As Kyle Chan, a post-doctoral researcher at Princeton University, noted in written testimony before the Commission, “China often employs not one but multiple strategies simultaneously, testing to see what works and then quickly doubling down on ones that appear to be gaining traction.”³⁸ For instance, as China prioritized the EV sector in the early 2010s, dozens of Chinese cities sought to become national hubs by offering generous direct subsidies, consumer subsidies to incentivize purchases, procurement contracts, cheap land, and tailored industrial parks to EV startups and battery firms.³⁹ While these policies, alongside national-level incentives, led to over-investment, with over 100 brands selling NEVs in 2024, they also helped foster several globally competitive EV companies, including BYD, NIO, and XPeng, that are now postured to dominate the sector on an enduring basis globally.*⁴⁰

Scope for Local Policy Experimentation Narrows as Xi Recentralizes Decision-Making

Though policy experimentation and local initiative continue to play key roles in Chinese industrial policy, central leaders have begun setting stricter bounds on local flexibility and improvisation.⁴¹ Since 2012, Xi has enshrined the concept of “top-level design” and worked to recentralize decision-making and ensure uniformity in policy execution at lower levels through more prescriptive policy frameworks.⁴² The rise in anticorruption probes under the Xi regime also raises the risks for local officials acting beyond the bounds of what the Party has explicitly authorized.⁴³ Although local discretion will retain a role on issues that are more peripheral to the central government's agenda, subnational governments are becoming more risk averse in adapting centrally defined policies to on-the-ground conditions.⁴⁴ Reflecting the decline in local policy autonomy, one longitudinal study of over three million Chinese industrial policies issued between 2000 and 2022 found that local policies have signaled their adherence to central policies more frequently since 2013, reversing a downward trend in references to higher-level policies that persisted until 2012.⁴⁵ As Jessica Teets, a political scientist at Middlebury College, testified before the Commission in 2022, “This is the era of authoritarian bureaucrats, and not policy entrepreneurs.”⁴⁶

*The number of NEV manufacturers has declined since 2018, when China had over 400 EV manufacturers. However, the industry remains overcrowded, and consultancy AlixPartners projects that only 15 Chinese EV brands will remain by 2030. Stephen Dyer and Yichao Zhang, “AlixPartners 2025 Global Automotive Outlook: China's ‘New Operating Model’ Redefines Speed, Efficiency, and Market Leadership in Automotive Industry Amid Accelerating Disruptions,” *AlixPartners*, July 3, 2025; Trefor Moss, “China Has 487 Electric-Car Makers, and Local Governments Are Clamoring for More,” *Wall Street Journal*, July 19, 2018.

Overcapacity and Managing Market Competition

Excess production and overcapacity—where the level of supply exceeds what domestic demand can absorb and causes the underutilization of industrial capacity—are systemic outcomes of China’s industrial policy.⁴⁷ Campaign-style mobilization of China’s entire government apparatus often leads policy support to overshoot expected market demand, resulting in excess entry and overinvestment.⁴⁸ As seen in numerous industries like active pharmaceutical ingredients (APIs), robotics, solar panels, and EVs, competition in the market drives down prices, eliminating weaker firms while stimulating demand for domestic brands.⁴⁹ While hyper-competition—where the market is fragmented between too many domestic firms for any to succeed—is often a byproduct of China’s industrial policies, it seeks to manage the risks by revising subsidies, adjusting barriers to foreign entry, and arranging industry-wide consolidations—but only after the strongest firms have gained sufficient scale and capability.⁵⁰ China often applies this approach to boost productivity in its state-owned sector as well, where the Party-state often maintains multiple state-owned enterprises (SOEs) in the same market to create “orderly” competition—enough to restrain some inefficiencies without wholly undermining their capacity to advance policy objectives.⁵¹

Multi-Pronged Strategy to Assimilate and Re-Innovate Foreign Technology

China views foreign manufacturing knowhow and the associated technology as core to its industrial strategy, and it uses a variety of tools to acquire foreign technology, promote its diffusion across the country, and support its assimilation and in some cases reverse-engineering.*⁵² China’s Medium- and Long-Term Plan for Science and Technology Development (2006–2020) explicitly identified “assimilation and absorption of imported technology” as a core driver of indigenous innovation.⁵³ One of the Party-state’s key tactics is to compel foreign companies into a variety of different arrangements that result in technology transfer deals. Additionally, the Party-state backs Chinese companies’ targeted acquisitions of high-tech Western companies. China also leverages Western multinationals to develop domestic component supply chains that can subsequently provide inputs to the foreign companies’ Chinese competitors. These component manufacturers themselves also emerge as competitors to established suppliers internationally. In parallel, China tries to recruit top foreign experts as well as encourage Chinese nationals in key science and

* China has articulated a four-step framework for absorbing foreign technology—Introduce, Digest, Assimilate, and Re-Innovate—commonly referred to as the IDAR system. “Introduce” refers to the targeting and importation of foreign technology and knowledge, which are then “digested” by China’s science and technology system and disseminated throughout China’s economy. “Assimilate” means to combine foreign technologies with local technologies, while “re-innovation” involves reverse-engineering the technology and developing capabilities to produce it domestically. IDAR has been promulgated by Chinese officials since the late 1990s, but it gained prominence in the Medium- and Long-Term Plan (2006–2020) period following the issuance of policy guidelines to support the IDAR approach. Tai Ming Cheung, *Innovate to Dominate: The Rise of the Chinese Techno-Security State* (Cornell University Press, 2022), 214–226; China’s Ministry of Commerce et al., 关于鼓励技术引进和创新，促进转变外贸增长方式的若干意见 [Opinions on Encouraging Technology Transfer and Innovation and Promote the Transformation of the Growth Mode in Foreign Trade], July 14, 2006.

technology roles to return to China through recruitment initiatives like the Thousand Talents Programs.* The ultimate objective is to create a self-reinforcing cycle whereby China achieves technological self-sufficiency and competitive advantage.

Forced Technology Transfer

China accelerated its techno-industrial development by coercing foreign companies into providing Chinese competitors access to their technology as a condition for market access.† One study found that the number of policies that targeted forced technology transfer in strategically important industries increased sixfold between 2006 and 2015.⁵⁴ Policies such as the Special Administrative Measures for Foreign Investment Access (also known as the Foreign Investment Negative List) require special approval for investment in China in specified sectors and often require foreign companies to establish joint ventures (JVs) with Chinese partners. China routinely utilizes both tools as leverage to demand foreign companies transfer technology to China as a condition for being allowed to invest in the market.⁵⁵ China uses the JV requirement to obtain access to foreign intellectual property (IP), promote the flow of skilled workers from the JV to the rest of the economy, foster a component supplier network that also serves the Chinese competition, and facilitate technology theft.⁵⁶ Chinese JV requirements and foreign ownership restrictions have relaxed in recent years with the implementation of the Foreign Investment Law in 2020 and revisions to the Foreign Investment Negative List—though many of these restrictions were lifted only after China had already extracted much of the foreign technology it needed.‡⁵⁷ Still, in 2024, 40 percent of surveyed U.S. multinational enterprises in China that shared technology with local partners reported that the government compelled them to do so as a condition for conducting ordinary business in the market.⁵⁸

China's acquisition of high-speed rail technology is illustrative. It required industry-leading foreign companies to form JVs with Chinese train makers. Seeing a once-in-a-century chance to profit from China's rail expansion, foreign firms transferred technology and knowhow in a quid pro quo for market access—helping cultivate their top global competitor in the process.⁵⁹ Today, China has deployed the largest and most advanced high-speed rail system on earth, with over 28,000 miles of track.⁶⁰ The flagship Beijing-Shanghai line covers 819 miles—roughly the distance from New York to Chicago—in just four and a half hours at speeds of 217 mph.⁶¹

*For more on China's talent programs, see Anastasya Lloyd-Damnjanovic and Alexander Bowe, "Overseas Chinese Students and Scholars in China's Drive for Innovation," *U.S.-China Economic and Security Review Commission*, October 7, 2020.

†For more, see Sean O'Connor, "How Chinese Companies Facilitate Technology Transfer from the United States," *U.S.-China Economic and Security Review Commission*, May 6, 2019.

‡By 2022, China removed all restrictions on foreign ownership in the automotive sector, terminating a 50 percent ownership cap that had been in place since 1994 and had forced foreign auto companies into JVs with Chinese partners. Foreign EV companies have been allowed to have wholly foreign-owned enterprises since 2018. Shunsuke Tabeta, "China Scraps Foreign Investment Curbs in Auto Sector," *Nikkei Asia*, December 28, 2021; "Chinese Carmakers under Pressure as Joint-Venture Caps Erased," *Bloomberg*, April 17, 2018.

Even when China faced barriers to acquiring leading-edge capabilities through forced technology transfers,* foreign firms more readily agreed to provide mature technologies and knowhow that were still more advanced than what was available domestically—playing a key role in upgrading Chinese industry’s position globally.†⁶²

Overseas Acquisitions

Chinese overseas investment has been a strategic and blunt tool for advancing domestic industrial capabilities and helping close China’s gap with the technology frontier. China’s government has provided financing support and technical assistance for acquisitions of Western companies and has encouraged Chinese entities to invest in foreign startups in high-tech sectors.‡⁶³ Since the launch of MIC2025, Chinese investments in key technologies and critical infrastructure have accelerated, ranging from semiconductors to biotechnology.⁶⁴ One study found that between 2014 and 2017, 112 Chinese direct investments in German companies—representing 64 percent of the total—took place in sectors related to the ten key technologies identified in MIC2025.⁶⁵ In industrial robotics, which was central to its MIC2025 ambitions, China was able to shortcut its way to global competitiveness through its controversial acquisition of the German robotics company Kuka (see textbox).⁶⁶ As discussed in the section “China’s Industrial Commons in Advanced Technology Manufacturing” below, the widespread adoption of robotics fueled productivity growth across China’s manufacturing sector. Chinese companies also acted opportunistically to acquire distressed U.S. tech companies in sectors aligned with the Party-state’s industrial policy priorities, capitalizing on Western firms’ decisions to abandon or sell legacy technologies and IP that remained relevant and in use but that the firms had deprioritized.⁶⁷

* John David Minnich, a professor at the London School of Economics, argued that Chinese officials were unable, and perhaps unwilling, to leverage market access to impose JV or tech transfer requirements on leading semiconductor firms. This is because in the early 2000s and into the 2010s, most chip imports into China went to its export manufacturing sector. Foreign-sourced chips were critical to China’s export manufacturing-led growth, and Chinese policymakers were unwilling to risk this export engine by imposing market barriers to force non-Chinese companies to transfer advanced technologies for market access, although many firms agreed to set up less advanced facilities. John David Minnich, “Scaling the Commanding Heights: The Logic of Technology Transfer Policy in Rising China,” *MIT Political Science Working Paper*, June 29, 2023, 31.

† One study of the auto sector found that forming a JV with foreign automakers improved the quality—as measured in J.D. Power surveys—of vehicles made independently outside of the partnership by as much as 12.7 percent from 2007 to 2014. In other words, these JV requirements successfully enlisted foreign companies to accelerate the development of China’s domestic auto champions, even if China’s auto sector still ultimately lags behind leading foreign brands in internal combustion engine vehicles. Jie Bai et al., “Quid Pro Quo, Knowledge Spillover, and Industrial Quality Upgrades: Evidence from the Chinese Auto Industry,” *NBER Working Paper*, September 17, 2023, 5.

‡ China has employed its whole-of-nation approach to boost investment in strategic assets. China’s Ministry of Science and Technology employs “science and technology diplomats” that are located in Chinese embassies and help Chinese companies by identifying and publicizing potential acquisition targets in key technology areas and playing match-maker by hosting conferences and other events, often in coordination with overseas United Front Work-linked entities. Companies pursuing these acquisitions benefit from tax exemptions and low-cost financing from China’s state-backed financial sector. Ryan Fedasiuk, Emily Weinstein, and Anna Puglisi, “China’s Foreign Technology Wish List,” *Center for Security and Emerging Technology*, May 2021; Elisabeth Braw, “How China Is Buying Up the West’s High-Tech Sector,” *Foreign Policy*, December 3, 2020; Thilo Hanemann and Daniel H. Rosen, “Chinese Investment in the United States: Recent Trends and the Policy Agenda” (prepared for the U.S.-China Economic and Security Review Commission), December 2016, 71–72.

Kuka Robotics Transaction Expands China's Control over Automation Tools

Chinese company Midea's unsolicited 2016 acquisition of the German company Kuka, a leading manufacturer of robotic arms and other industrial robotics used to automate production lines, accelerated its effort to shape the next generation of advanced manufacturing. MIC2025 identified smart manufacturing and automation as drivers of a manufacturing transformation, making the development of a domestic robotics industry a top priority.⁶⁸ China's biggest step toward this goal came when the Chinese appliance manufacturer Midea acquired Kuka in a transaction valued at \$5 billion.⁶⁹ Midea initially acquired a small stake in Kuka in late 2015. Over a few months it quickly expanded its interest to 30 percent while claiming that it had no intention to gain controlling shares or acquire the company; a few weeks after such statements, Midea mounted a takeover effort.⁷⁰ Though some German commentators in 2016 recognized the risk of transferring technological leadership to China, and Chinese official sources directly linked the takeover to MIC2025, the German government did not obstruct the deal.⁷¹ Today, Kuka has six robotics factories inside China, and its robots are ubiquitous in facilities throughout the country, including in advanced sectors like satellite and rocket manufacturing.⁷² Kuka remains the only Chinese-owned industrial robotics firm in the top 10 largest globally, suggesting that homegrown Chinese competitors have yet to replicate its success.⁷³ Nonetheless, the acquisition catalyzed Beijing's effort to dominate key tools of production, which Liza Tobin, managing director of risk advisory Garnault Global, described as "the base layer of machines, materials, and systems that determine who can manufacture and who cannot and who reaps the benefits of innovation."⁷⁴

Indirect Technology Transfer through Shared Supplier Spillovers

Multinational companies played an instrumental role in catalyzing the growth of China's innovation and entrepreneurial ecosystem and training top Chinese engineering talent at firms that became competitors to U.S. and other foreign counterparts. (See also "Foreign Direct Investment's Role in Developing China's Advanced Industrial Commons" box below.) China incentivized foreign partners to help develop domestic supply chains that diffused knowledge to local firms, resulting in industry-wide benefits to China. Many U.S. tech firms acted as supply chain architects within China that worked alongside Chinese suppliers to enhance their production capabilities

*Following the Kuka acquisition, the German government revised its legal framework for investment screening to cover a broader range of transactions. Additionally, the European Commission enacted an EU-wide investment screening framework, although only 24 of the 27 EU member states have adopted the voluntary framework. For more, see U.S.-China Economic and Security Review Commission, Chapter 5, Section 1, "Europe-China Relations; Convergence and Divergence in Transatlantic Cooperation," in *2023 Annual Report to Congress*, November 2023, 544; European Commission, Directorate-General for Trade and Economic Security, *Foreign Direct Investment Screening Continues to Boost EU Economic Security*, October 14, 2025; Cynthia Wraga and Jakob Kulik, "After Kuka—Germany's Lessons Learned from Chinese Takeovers," *China Observers in Central and Eastern Europe*, July 21, 2022.

and quality. The efforts of U.S. companies like Apple and Tesla to foster a network of suppliers for their own products simultaneously created an ecosystem of firms that could support China's own tech companies.⁷⁵ Journalist Patrick McGee argued "China would not be China today without Apple ... [which,] in feeding its own global ambition, helped fuel China's technological rise." According to his reporting, Apple constructed—rather than merely outsourced—its supply chain by embedding designers and engineers in Chinese suppliers and investing billions to install custom equipment within these firms.⁷⁶ Many of these companies would go on to also supply Apple's Chinese competitors, such as Vivo and Oppo.⁷⁷ Tesla's investment in China provides another example where foreign firms helped develop Chinese advanced manufacturing supply chains. As part of its investment, Tesla partnered with Chinese firm LK Group to design and create its "giga-press"—a large-scale machine capable of casting an entire car frame in a single piece in just 100 seconds, an important technology for Tesla's manufacturing process.⁷⁸ LK Group then reportedly shared this technology with other companies in China, including EV newcomer Xiaomi, giving them the same critical advantages Tesla once possessed in EV manufacturing.⁷⁹ Western firms, including Apple, Microsoft, and Cisco, also supported the growth of China's innovation ecosystem through investments in R&D centers and startups.⁸⁰ Experts note that these investments were often part of explicit or implicit agreements with Chinese officials to gain favorable regulatory treatment and market access.⁸¹

Co-opting Market Mechanisms to Advance State Policy Goals

Recognizing that SOEs were often ill-equipped to pursue innovative technology development initiatives, China has introduced novel mechanisms to increase private-sector participation and reward success. Beijing believes it can combine state guidance with market-based competition to create sandbox-like environments that provide innovative firms resources and support to engage in risky experimentation and iterative innovation while setting boundaries for where such activity takes place.⁸² To overcome a bias toward SOEs and large firms within China's financial system that deprives smaller companies of capital, China has established a system of targeted mechanisms to help domestic small and medium-sized enterprises (SMEs) scale and replace foreign suppliers, often in markets for specialized components.⁸³ This system includes initiatives like the "Little Giants" program that was launched in 2018 and aimed to identify 10,000 innovative SMEs. Rather than picking a winner *ex ante*, this approach aims to identify a champion through tournament-style competition that encourages entry and risk-taking by multiple firms while withdrawing support from those that lag behind.⁸⁴ For instance, China has at least seven companies attempting to commercialize reusable launch vehicles and compete with industry leader SpaceX.⁸⁵

China's Industrial Policy Arsenal

To operationalize the strategies in MIC2025, China has deployed a latticework of mutually reinforcing policy instruments to steer the trajectory of innovation and industrial upgrading, including:

- *Market entry barriers:* China systematically shields domestic companies from foreign competition through market access barriers and informal restrictions that create an uneven playing field, such as skewing preferential public procurement policies toward domestic firms, manipulating the licensing process, and creating lengthy approval delays for foreign competitors.⁸⁶ Examples abound of domestic industries where China created an artificial home market advantage, such as in solar panels and medical devices.⁸⁷ These discriminatory policies align with China's industrial priorities, aiming to give domestic competitors a protected foothold in the home market and the opportunity to achieve economies of scale before facing global competition. This strategy has proven effective in sectors like telecommunications and high-speed rail, where protected domestic champions eventually became global exporters.
- *Subsidies, tax breaks, and financial incentives:* In addition to subsidies through directed financial support, Chinese policymakers use R&D tax incentives, cheap capital, below-market land sales, worker repression and forced labor,* favorable regulatory treatment, and other tactics to implement industrial policy. Unsurprisingly, measuring the full breadth of China's subsidies policies is challenging, in part by design as transparency around state support would open China to challenges within the WTO. Even comprehensive studies on the topic acknowledge that lack of transparency, and data gaps mean they likely capture only part of the picture. One study estimates that Chinese industrial policy spending in 2019 totaled 1.73 percent of gross domestic product (GDP) (roughly \$250 billion), including \$54 billion in direct subsidies, \$65 billion in R&D and other tax incentives, and \$74 billion in below-market credit, more than any other economy.⁸⁸
- *Forced technology transfer policies:* Beijing utilizes a range of measures to extract technology from foreign firms, including compelling foreign firms to form JVs with state-connected Chinese partners, licensing requirements that include technical information disclosures,† mandatory technology transfer agreements as conditions for market access, and systematic cyber and corporate espionage (for more, see "Multi-Pronged Strategy to Assimilate and Re-Innovate Foreign Technology" above).

*China's polysilicon and solar panel industry is complicit in the CCP's Uyghur forced labor system. In addition to lowering the unit costs of production, Chinese companies were provided tax incentives for participating in forced labor transfers initiatives. The United States has taken several steps to counter the use of forced labor in the solar supply chain, including when the U.S. Customs and Border Protection issued a Withhold Release Order in 2021 against Hoshine Silicon Industry, one of the world's largest silicon producers, over its use of forced labor in Xinjiang. U.S. Customs and Border Protection, *The Department of Homeland Security Issues Withhold Release Order on Silica-Based Products Made by Forced Labor in Xinjiang*, June 24, 2021; Laura T. Murphy and Nyrola Elimä, "In Broad Daylight: Uyghur Forced Labour and Global Solar Supply Chains," *Sheffield Hallam University Helena Kennedy Centre for International Justice*, 2021.

†China may be utilizing its new export control licensing regime to obtain sensitive information from foreign buyers. The *Financial Times* reported in June 2025 that companies seeking approval to export certain rare earths and critical minerals that are subject to Chinese export controls are being asked to provide production details, including pictures and video of production lines, as well as confidential lists of customers. Ryan McMorro, Joe Leahy, and Kana Inagaki, "China Demands Sensitive Information for Rare Earth Exports, Companies Warn," *Financial Times*, June 12, 2025.

- *Equity investment and government guidance funds (GGFs):* Over the past decade, China has created new financial tools and expanded state-backed funding channels to catalyze investment in startups and innovative small firms. GGFs are financial instruments that have become one of Beijing's primary means for directing financial resources toward priority sectors since 2014. Rather than making equity investments directly, GGFs seek to harness financial markets by operating as funds-of-funds, where they contribute capital as limited partners to venture capital and private equity firms.⁸⁹ By the first half of 2024, there were 2,126 GGFs with target allocations totaling \$1.8 trillion (12.8 trillion RMB), more than half the size of assets under management in the entire U.S. private equity market, although only roughly one-quarter of funds met their fundraising goals, according to one study based on 2021 data.⁹⁰ To create exit opportunities for startup equity investments, China established the STAR Market in 2019 and the Beijing Stock Exchange in 2021, both of which are designed to serve Little Giants and other SMEs.⁹¹
- *Manufacturing Champions and Little Giants:* China has deployed tiered support programs to nurture globally competitive companies that dominate niche markets for advanced technologies and components.⁹² China's Ministry of Industry and Information Technology (MIIT) launched a program in 2016 to boost the competitiveness of "manufacturing champions," firms that are leading producers of specialized technologies, with a particular focus on sectors targeted in MIC2025.⁹³ In 2018, it launched the Little Giants program to support SMEs competing in emerging technologies, with more explicit focus on filling gaps in supply chains that are currently dominated by foreign firms.⁹⁴ The government selects and certifies Manufacturing Champions or Little Giants in batches, based on a range of criteria including market share in an industrial policy priority area and the fulfillment of specific financial thresholds.* This certification effectively acts both as a "golden ticket" to a range of government benefits—including direct subsidies, preferential access to lending and investment, and cheaper access to land, labor, and energy—and as a signal that boosts credibility with the state-dominated financial sector.⁹⁵ Continued support is contingent on meeting specific key performance indicators, with the threat of withdrawal designed to incentivize companies to remain innovative.⁹⁶ As of July 2023, 12,756 SMEs have received the "Little Giants" golden tickets, and over 1,100 companies have received the "Manufacturing Champions" title.⁹⁷
- *Procurement:* China's massive public procurement market—which exceeded \$6.6 trillion in 2022—provides the government with a powerful lever it has used to generate demand for do-

*One of the criteria for receiving this status is operating in a MIC2025 priority sector, but in practice China has applied this standard loosely. Many companies receive support despite a lack of specialization in advanced technology. Alicia García-Herrero and Michal Krystanyanczuk, "How Does China Conduct Industrial Policy: Analyzing Words versus Deeds," *Journal of Industry, Competition and Trade* 24, no. 10 (2024): 14–16; Alexander Brown, François Chimits, and Gregor Sebastian, "Accelerator State: How China Fosters 'Little Giant' Companies," *MERICs*, August 3, 2023, 4.

mestic production, often through discriminatory policies that prevent foreign firms from competing for contracts.⁹⁸ For example, Chinese procurement in the medical device market, where China's largely state-owned hospital system provides the government a near monopsony, has included specific local content ratios for items including X-ray machines, MRI systems, and surgical equipment—all technologies targeted in MIC2025.⁹⁹

- *Megaprojects*: Alongside sectoral and industry-specific policies, China has designated a number of key technologies as megaprojects—national flagship initiatives backed by massive state funding that are closely coordinated and often directly overseen by the central government.¹⁰⁰ The Medium- and Long-Term Plan (2006–2020) contained 16 megaprojects, including the C919 narrow-body passenger airplane (now in commercial service), the BeiDou Navigation Satellite System (now providing global coverage), and hypersonic vehicle technology (successfully tested with global orbital capability in 2021).¹⁰¹ In 2015, China launched its Science, Technology, and Innovation 2030 Major Projects, which introduced another 16 megaprojects, such as quantum communications, deep-space exploration technologies, and AI.¹⁰² These initiatives represent China's most ambitious bets on breakthrough technologies deemed critical for national competitiveness and security.
- *Industrial zones*: China has established hundreds of high-tech industrial zones aimed at fostering clusters of innovative activity, the most prominent of which are the 173 National High-Tech Industrial Development Zones.¹⁰³ Beyond providing infrastructure for industrial development and fostering externalities from agglomeration, these zones serve as testing grounds where local officials deploy industrial policy tools and pilot programs.¹⁰⁴ Many zones explicitly target MIC2025 priority sectors, with clusters specialized in robotics, biotechnology, advanced manufacturing, and others.¹⁰⁵ This zone-based approach allows China to test policies on a smaller scale before national rollout.*

Inefficiency and Economic Headwinds Unlikely to Constrain CCP Industrial Policy

By directing resources at scale toward techno-industrial objectives, Beijing's approach creates significant economic costs, wasteful spending, and other unintended consequences that distort its own economy. One study examined how direct government subsidies, including those linked to MIC2025, impacted the performance of Chinese-listed firms, finding that subsidies did little to boost productivity and appeared to be allocated toward less productive firms—in other words, Chinese officials may more often pick losers rather than winners.¹⁰⁶ Other experts have linked the decades-long decline in China's total factor productivity growth to misallocation and distortions caused by China's market interventions.¹⁰⁷ More generally, industrial policy missteps take time to unwind, meaning

*Industrial zones provided benefits beyond just financial support, often acting in effect as consultants, helping firms navigate permitting and Chinese bureaucracy. Jonas Nahm, "China's Specialization in Innovative Manufacturing," in *Collaborative Advantage: Forging Green Industries in the New Global Economy* (Oxford University Press, 2021), 140.

that capital and labor are effectively trapped in underperforming firms or sectors until they can be redistributed to more productive uses. For example, China's EV sector is grappling with the fallout from overinvestment and the influx of underperforming entrants.¹⁰⁸ In the chip industry, an intensification of state support for semiconductor projects created waves of new entrants since 2019—including over 13,000 businesses that registered in 2020 alone—that likely fragmented the market among too many players.¹⁰⁹ The *Financial Times* reported in August 2025 that the government is attempting to consolidate the chip sector through a megamerger but has struggled to attract buyers, as many semiconductor firms lack competitive business models and are unattractive acquisition targets for potential domestic suitors.

The CCP's goal is not to maximize efficiency or capital allocation, however; to state the obvious, Xi Jinping does not believe Western-style capitalism is a superior macroeconomic system to China's state-led model.* From the perspective of China's leaders and their goals, Chinese industrial policy has had significant successes. A decade since it launched MIC2025, China achieved many of the plan's overarching goals and has rapidly built domestically—and, in many cases, globally—competitive capabilities across its ten targeted technologies.† It achieved across-the-board successes in EVs, space, electrical equipment, and biopharma while making significant progress in the other sectors in terms of increased global market share, localization of production, reduced reliance on foreign suppliers, or the development of domestic capabilities in leading-edge technologies.‡ While China fell short of MIC2025 targets in several sectors—most notably advanced semiconductors and commercial aviation—despite extensive support, these setbacks did not negate the policy's effectiveness in other areas. The rapid rise of China's EV industry exemplifies how targeted state support can deliver incredible results, even at the cost of incredible waste, transforming China from a negligible player to the world's largest EV market and exporter in less than a decade.¹¹⁰

Some commentators have argued that China's economic downturn will act as a constraint on China's industrial policy, particularly at the local government level. China's economic growth has been slowing since 2007, and it has experienced significant economic challenges since the beginning of the real estate sector crisis in 2021. Prospects for robust future growth face numerous headwinds, including an acute debt burden, long-term demographic decline, and structural imbalances stemming from persistently weak consumption, over-

*Further, China's system means the government has little direct responsibility to the people for waste, fraud, abuse, and political favoritism. There is little negative consequence in terms of public opinion and none in terms of electoral backlash with respect to the failures of China's industrial policy.

†For an evaluation of China's performance toward its MIC2025 goals, see Daniel Blaughner, Benton Gordon, and Matthew Dagher-Margosian, "Made in China 2025: Evaluating China's Performance," *U.S.-China Economic and Security Review Commission*, November 2025.

‡MIC2025 helped boost China's overall manufacturing capacity—which rose from 25.9 percent of global value added in 2015 to 28 percent in 2023—and global market share—with China-based firms accounting for nearly one-quarter of the global growth in exports related to the ten MIC2025 sectors between 2015 and 2023. Within MIC2025-related products, just under 20 percent of global exports in 2023 originated from China. World Bank Group, "Manufacturing, Value Added (Current US\$)"; Commission staff analysis based on CEPIL, "BACI 202401b HS07," "Market Power of China's Made in China 2025 Exports," *MITRE* (prepared on behalf of U.S. Air Force, Office of Commercial and Economic Analysis), July 29, 2022.

investment, and other factors (for more, see Chapter 1, “U.S.-China Economic and Trade Relations (Year in Review)”).¹¹¹ Local governments have faced deteriorating fiscal conditions as Beijing is attempting to rein in off-balance-sheet borrowing, including through local government finance vehicles (LGFVs), severely constraining localities’ ability to independently generate revenue—much of which is used to service debt raised through LGFVs.¹¹² As a result, localities across China have been forced to cut expenditures across a range of government services. In the face of these headwinds, some experts argue that China will face fiscal constraints that force it to cut back on its industrial policy expenditures to preserve space for other priorities.

While all governments face decisions about how to allocate scarce government spending, particularly during periods of declining growth, China is not likely to forego spending on industrial policy.*¹¹³ First, China’s industrial policy, while massive compared to other countries,† accounts for a relatively small part of China’s total government expenditures. According to a widely cited 2022 Center for Strategic and International Studies report, a lower bound estimate for the combined value in 2019 of Chinese government subsidies, direct R&D support, the provision of below-market credit, and state investment funds, amounted to roughly 3 percent of the government’s total fiscal spending. This figure, however, does not capture other forms of state support discussed above that are not recorded as government expenses.¹¹⁴ A 2025 working paper from the International Monetary Fund employing looser assumptions placed industrial policy spending at 4.4 percent of China’s GDP in 2023, though the study authors caveat that their methodology may overestimate subsidies in certain ways.‡

Second, the CCP clearly places a high priority on its industrial policy and believes it is key to its overarching economic and military goals. Since the release of the 2006–2020 Medium- and Long-Term Plan, the ambition and scope of China’s industrial policy have steadily grown. China has drawn an ever-larger share of the Party-state apparatus into pursuing these objectives, as reflected in the proliferation of industrial policy documents at all levels of government that target advanced industries.¹¹⁵ This evolution culminated in the emergence of a “new-style whole-of-nation sys-

*Analysis by the Rhodium Group argued that fiscal constraints are already leading to a slow-down in grants to publicly traded companies. Since 2020, total grants to listed firms in strategic sectors—excluding batteries and EVs—have largely stagnated, potentially reflecting increased risk aversion by local officials facing severe budget constraints. However, China is unlikely to materially downshift support to its top industrial priorities. Camille Boullennois, Endeavour Tian, and Laura Gormley, “The Mountain Is High, the Lead Investor Is Far Away,” *Rhodium Group*, September 9, 2024.

†Up-to-date estimates on the full scale of China’s industrial policy spending are unavailable, but recent estimates indicate that Chinese government support far outstrips any other economy. The Center for Strategic and International Studies found that, in 2019, China’s industrial policy spending totaled 1.73 percent of GDP. By comparison, the researchers applied the same methodology to seven other major economies, including the United States, and estimated spending at between 0.3 and 0.7 percent of GDP. Gerard DiPippo, Ilaria Mazzocco, and Scott Kennedy, “Red Ink: Estimating Chinese Industrial Policy Spending in Comparative Perspective,” *Center for Strategic and International Studies*, May 2022, 32–33.

‡The study assumes subsidy rates for non-listed firms are the same as publicly traded firms, which disclose certain subsidies like R&D grants in their financial statements. However, publicly traded companies tend to be larger firms or SOEs and may have higher subsidization rates than other companies. Daniel Garcia-Macia, Siddharth Kothari, and Yifan Tao, “Industrial Policy in China: Quantification and Impact on Misallocation,” *IMF Working Paper*, August 8, 2025, 4–12.

tem,” a concept Beijing formalized as a key driver of its techno-industrial approach in the 14th Five-Year Plan (2021–2025).¹¹⁶ The system entails a governance model that enables Beijing to coordinate across the public and private sectors to deploy resources at scale to break through technological barriers and challenges.¹¹⁷ China adjusted its cadre evaluation system—through which local officials are assessed for promotion within the state bureaucracy—by incorporating key performance indicators tied to the Party-state’s techno-industrial objectives.¹¹⁸ As discussed above, Beijing sees its innovation drive as critical to overcoming the challenges confronting the Chinese economy, society, and national security. In 2024, Xi emphasized that China must develop new growth drivers in order to propel overall productivity and innovation, underscoring the Party-state’s view that technological progress can address not only China’s technological vulnerabilities but also its broader economic headwinds.*¹¹⁹

Given the importance the Party-state places on industrial policy in helping China achieve a variety of goals, when faced with tradeoffs, Xi will prioritize China’s technology and industrial policy ambitions over other policy objectives. While local governments may face more fiscal challenges than the central government, to date the economic slowdown has not materially affected their capacity to fund high-tech enterprises. As local government balance sheets have deteriorated, officials have largely cut spending on areas such as community services and domestic security.¹²⁰

To the extent that China’s economic headwinds impact the outcomes of its industrial policy, the result is likely to be a two-speed economy where rapidly growing targeted (often high-tech) sectors receiving government support coexist with a broader macroeconomic slowdown. In this case, Chinese policymakers *may* scale back investments in smaller, riskier companies and instead focus on larger companies, SOEs, and priority sectors that are better established and are already significant local employers.¹²¹ Between 2020 and 2023, the median grant size awarded to listed firms in strategic sectors—excluding batteries and EVs—have largely stagnated, even as the average grant value increased by roughly 30 percent, potentially reflecting a greater concentration of support to larger firms over smaller as local officials minimize risks given tighter budget constraints.¹²² Support for EVs, batteries, SOEs, and the largest 200 listed companies has continued to grow.¹²³

Industrial Commons Provides Foundation for Continued Manufacturing Leadership

China’s industrial policies are more than the sum of their parts. While China counts numerous successes in meeting sector-specific goals, the greatest gains are not in market share in a

*In this regard, China appears to be ignoring evidence to the contrary. Although output growth from high-tech manufacturing sectors exceeded total manufacturing output in 2024, China’s economy as a whole is struggling to regain its footing. As observed by RAND senior researcher Gerard DiPippo, “China’s high-tech industries are only a small share of its total economy. Those high-tech sectors shaping the ‘new economy’ are indeed growing, but they are not large enough to offset overall weakness in the ‘old economy’ weighing down key indicators like GDP growth.” Gerard DiPippo, “Focus on the New Economy, Not the Old: Why China’s Economic Slowdown Understates Gains,” *RAND*, February 18, 2025.

specific sector or value-added growth but rather in the industrial commons fostered by MIC2025 and related policies. “Industrial commons” encompasses the interdependent capabilities, resources, skills, and institutions that underpin competitive manufacturing. These elements work collectively to strengthen the entire ecosystem. During the past decade, China’s mutually reinforcing investments in production capacity, scientific infrastructure and talent, supply chain development, and the pipeline from applied research to commercialization have created emergent capabilities in advanced manufacturing and innovation beyond the objectives of any single industrial policy. These cumulative advances in China’s manufacturing ecosystem have now laid the foundation for rapid progress in other emerging sectors.

The next section discusses China’s industrial commons and the related phenomenon of “interlocking innovation flywheels,” or the cumulative and mutually reinforcing gains as innovative breakthroughs in one field drive advances in adjacent technologies. Case studies demonstrate how industrial policy fostered foundational, interdependent capabilities that now position China to succeed in emerging technologies that combine skills, knowledge, and production processes across multiple advanced fields.

China’s Industrial Commons in Advanced Technology Manufacturing

Harvard Business School professors Gary Pisano and Willy Shih are credited with popularizing the “industrial commons” concept and noting its importance to manufacturing competitiveness, innovation, and economic growth.¹²⁴ When a country achieves a core foundation of manufacturing capacity—including capital assets, component supply chains, a skilled workforce, R&D infrastructure, experience moving from prototype to product launch, enhanced knowhow, and capacity to undertake iterative process improvements—it forms a virtuous circle in which these elements can reinforce and strengthen each other. This “industrial commons” enhances a country’s ability to produce, scale, continuously improve, and design more complex products, leading to efficiencies and advanced capabilities in overlapping sectors.¹²⁵ Closely related to “industrial clusters” described above but acting on a much broader scale, production advantages from industrial commons have been core to numerous industrial success stories.

Over the past two decades, China has developed the world’s most extensive industrial commons in advanced manufacturing, first by developing foundational capabilities across a range of sectors, then by systematically moving up the value chain and expanding into new fields. By MIC2025’s launch in 2015, China was already the world’s largest manufacturer, a position it attained partly by progressing from low-value-added assembly of components produced elsewhere to developing a robust industrial ecosystem of domestic suppliers.¹²⁶

China’s deep manufacturing sector provides it numerous advantages. It has extensive production links across a wide variety of industrial sectors, which now generate broader manufacturing-wide clustering and spillover effects that speed up innovation.¹²⁷ China

provides a massive base of manufacturing suppliers capable of providing a particular manufacturing service or making a specific component.¹²⁸ As Jay Goldberg, founder of tech consultancy D/D advisors, stated, “There’s all these subcontracted, specialty niche firms, and nowhere else does that exist... in the world.”¹²⁹ Its manufacturing sector also facilitates more and faster linkages between different elements of the manufacturing ecosystem, including co-location of manufacturing and R&D, upstream and downstream suppliers, contract research, digital prototyping, and training.¹³⁰ Manufacturing companies and workers in China now have extensive experience innovating on factory production lines, iterating processes, and enhancing efficiencies.¹³¹

Adding to its strong industrial commons is the scale of China’s manufacturing sector, which provides certain advantages on its own. Apple CEO Tim Cook once tried to explain China’s manufacturing scale, telling an audience that if every tool and die maker in America were invited to the auditorium where he was speaking, they “wouldn’t fill the room.” Whereas “in China,” he added, “you would need several cities to fill with tool and die makers.”¹³² With an internal market equal to nearly 20 percent of global GDP (on a purchasing power parity [PPP] basis) and the largest manufacturing export sector in the world, China provides manufacturers an opportunity to produce and sell at scale that can be particularly beneficial to a variety of manufacturing industries.¹³³

While MIC2025 and related policies focused on advanced and emerging sectors, they concomitantly enhanced China’s existing industrial commons for the entire manufacturing sector. MIC2025 helped Chinese firms integrate existing strengths into new technologies and products and supported investments that improved manufacturing processes across the board. For instance, machine tools and automation are core manufacturing capital assets that enhance industrial capability in a variety of sectors. China’s support in MIC2025 for precision machine tools and industrial automation tools have helped a broad range of Chinese manufacturers become more efficient, remain cost competitive as wages increase, and close the gap in most sophisticated manufacturing processes with other advanced economies.¹³⁴ Even industries that were not directly targeted by MIC2025, such as China’s consumer electronics industry, benefited from MIC2025’s support in these sectors. As a result, China was able to grow its already outsized share of global manufacturing value added even more.

Robotics and Intelligentization as Key Elements of China’s Manufacturing Industrial Commons

As discussed above, one of China’s core goals in MIC2025 was to encourage “intelligentization” across its manufacturing ecosystem, or enhanced use of automation, digitization, AI, and robotics to reduce production costs and increase efficiency. It was very successful. In 2015, China’s industrial robot density (defined as industrial robots per 10,000 workers) was only 19, compared to 176 in the United States and 531 in South Korea; China was not even in the top 20 globally (Australia was 20th, with a density of 86, more than four times China’s at the time).¹³⁵ Respected German think tank the

Mercator Institute for China Studies (MERICS) observed in 2016, “Most Chinese factories feature a rudimentary level of automation and almost no digitization.”¹³⁶ In 2019, China entered the global top ten in robot density and by 2023, China’s manufacturing sector had become the third most automated in the world with an industrial robot density of 470, behind only Singapore and South Korea.¹³⁷ China now leads the world in total robot installations: in 2023, it reached 1.76 million units operational in factories, accounting for 41 percent of all operational global stock and more than half of new installations in the preceding year, according to the International Federation of Robotics.¹³⁸

China’s rapid installation of industrial robots contributes to China’s industrial commons in important ways. Robotic automation improves quality and reduces costs. A recent study found an approximate 10 percent increase in total factor productivity (TFP) among manufacturing firms from industrial robot adoption.¹³⁹ Other studies have also found significant increases in productivity from industrial robotics automation.¹⁴⁰ Of the 276,000 robots installed in China during 2023, the electronics industry led with over 77,000 installations, followed by automotive with nearly 65,000 units and metal and machinery with more than 41,000 units.¹⁴¹ Grace Shao, founder of Hong Kong tech consultancy AI Proem, noted that China’s installations “cluster where speed and precision pay immediate dividends” like fastening, testing, and packaging circuit boards for complex electronics products or welding and painting in factories—in other words, capabilities with numerous industrial applications.¹⁴² Taiwan contract manufacturer Foxconn was an early leader in automation in Chinese electronics factories, reportedly replacing 60,000 workers with robots in its Kunshan factory in 2016.¹⁴³ Other consumer electronics companies have followed suit, with Xiaomi building a “dark factory” with minimal human intervention in Changping that reportedly produces a smartphone every three seconds.¹⁴⁴ Xiaomi’s EV factory near Beijing reportedly is 91 percent automated and can produce an EV every 76 seconds.*¹⁴⁵

Beyond labor savings, smart factories can operate “lights-out,” producing continuously without lights and with minimal climate control. Gree Electric Appliances, China Unicom, and Huawei report that their 5.5G-networked lights-out factory, the world’s largest, increased production efficiency by 86 percent.¹⁴⁶ As demand for robotic automation has increased, as by far the leading global installer of new industrial robots, China’s manufacturing sector is developing knowhow in optimal automated factory design.¹⁴⁷ Strong domestic demand is also driving down costs and improving local robotics manufacturing and innovation capabilities. Although China continues to source a majority of its robots from foreign firms (including foreign firms’ operations in China), in 2023 local purchases rose to 47 percent after hovering around 28 percent for a decade, while installations of foreign-made robots fell 21 percent.¹⁴⁸

* China’s automotive industry is number two in the country in terms of robot density. “Record 1.7 Million Robots Working in China’s Factories,” *International Federation of Robotics*, September 24, 2024.

Foreign Direct Investment's Role in Developing China's Advanced Industrial Commons

China's outsized role in manufacturing mobile phones, tablets, personal computers, and smart appliances owes to its success in attracting foreign direct investment (FDI) and working with multinational companies to improve the ability of Chinese supply networks to manufacture quality—and in some cases cutting-edge—electronic components.

Supplier relationships with Apple have been instrumental in positioning Chinese firms at the forefront of consumer electronics manufacturing capabilities. Of Apple's total supply chain in 2023, 157 of its manufacturing or component suppliers were either Chinese or based in China.¹⁴⁹ As of 2023, 95 percent of iPhones, AirPods, Macs, and iPads were made in China.¹⁵⁰

Apple's reliance on China for parts and assembly has been driven partly by pressure from Chinese officials demanding commitments to train Chinese engineering talent and strengthen production processes in order to continue to benefit from its supply network there.¹⁵¹ This Chinese government "pay to play" tactic led to a 2016 memorandum of understanding under which Apple agreed to invest \$275 billion to support the development of China's tech ecosystem over a five-year period, including through collaborating with Chinese universities and investing in local tech firms.¹⁵² In comparison, the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022 allocated \$52.7 billion over five years to support U.S. domestic semiconductor manufacturing, research, and development.¹⁵³

As it designs new features and specifications for future product generations, Apple has traditionally worked closely with its supplier network in China to conduct R&D on technical advances and develop the manufacturing processes that bring design concepts into production.¹⁵⁴ As part of this process, Apple embedded engineers at more than 1,600 Chinese partners, helping improve efficiency; it has even bought advanced machinery for some suppliers.¹⁵⁵ For example, Apple collaborated with touchscreen manufacturer Lens Technology to develop new laser technology for glass cutting the full screens on iPads and iPhones, a technology which is now an industry standard.*¹⁵⁶ Apple and Lens Technology reportedly continue to collaborate to produce advanced ultra-thin glass used for flexible screens.¹⁵⁷

Investments and partnerships with foreign companies helped grow China's broader electronics industrial sector, contributing to its status as the world's largest producer of consumer electronics, accounting for 54 percent of global exports in 2023.¹⁵⁸ Some of the largest and most sophisticated Chinese consumer electronics firms are key components suppliers to foreign brands. Lens Tech-

*According to Apple's COO Jeff Williams, "It was actually a big challenge at the time, because no one used glass materials in large-screen mobile phones at that time. We worked with Chairman Zhou to overcome difficulties and make the product." Ni Yuqing, "‘果链’崛起 苹果巨资再押中国智造" [The Apple Supply Chain Rises: Apple Places Another Massive Bet on Chinese Manufacturing], *21st Century Business Herald*, October 25, 2024.

FDI's Role in Developing China's Advanced Industrial Commons—*Continued*

nology is now the world's largest manufacturer of touchscreens.¹⁵⁹ Acoustic components maker Goertek is a longtime supplier to Sony and Apple; a subsidiary of the firm also manufactures 80 percent of global medium-to-high-end virtual reality headsets and won a German award for its flexible smart glasses.*¹⁶⁰ Apple iPhone camera lens provider Sunny Optical is now the world's largest smartphone lens supplier, and the firm currently retains a large market share in computer vision and navigation for robotic vacuum cleaners.†¹⁶¹

Repeating a story seen in other sectors, many of the Chinese firms cultivated by foreign firms are now global competitors. Chinese suppliers to the consumer electronics industry have played pivotal roles in building up local competitors like Huawei and Xiaomi. Teardowns of Xiaomi's phones reveal components from Chinese suppliers that also have worked with leading international brands (see Table 1).

Table 1: Xiaomi Suppliers Overlap with Samsung and Apple

Supplier	Component	Overlap
Sunny Optical	Camera lenses	Apple
Sunwoda	Batteries	Apple
Goworld	"One-glass" touchscreens	Apple
Janus Precision	Structural components	Samsung
Shenzhen Zowee Tech	Portable power banks	Samsung
Shenzhen Aisidi Co., Ltd	Distribution	Samsung, Apple

Source: Various.¹⁶²

China's Interlocking Innovation Flywheels

China's deepening of its industrial commons and sustained support for advanced and emerging technology sectors during the MIC2025 period have now fostered the capacity for overlapping, mutually reinforcing innovations in adjacent technologies. These "interlocking innovation flywheels" (IIFs) are leading to heightened levels of innovation across China's manufacturing ecosystem. Incremental advances in one technical application support progress in another area, in turn enabling gains in related technologies or products in a self-reinforcing cycle. In other words, China's enhanced innovation capacity and competitiveness in sectors supported by industrial policy fuel its innovation capacity across multiple additional technologies. As research consultancy Rhodium Group observed regarding MIC2025 implementation:

* Goertek's augmented and virtual reality device subsidiary, Goertek Optical, was designated for state support under the fourth tranche of Little Giants.

† China's MIIT designated Sunny Optical in the fifth tranche of Little Giants.

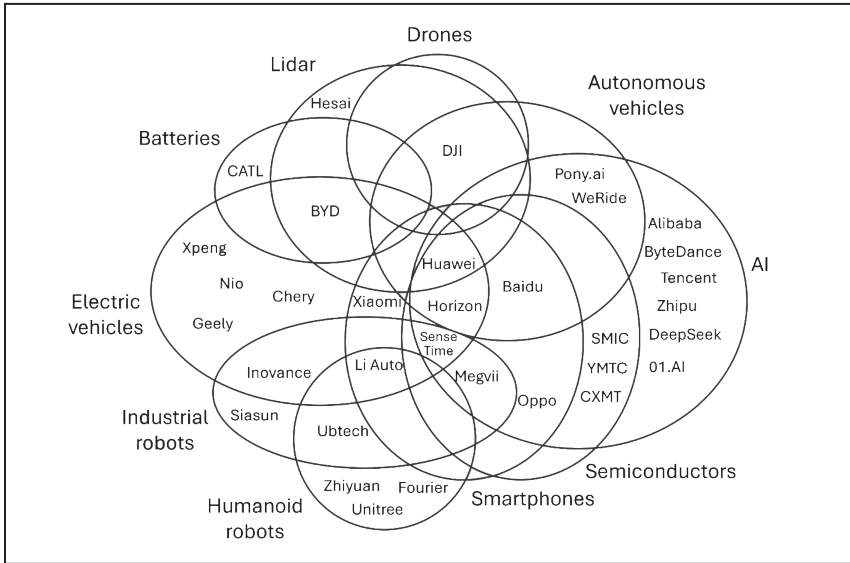
*[O]verlapping technological achievements across sectors have arguably created a reinforcing effect that will amplify China's progress and grip over global supply chains in the years to come. Strengths in foundational technologies such as advanced materials, semiconductors, and artificial intelligence catalyze advancements in downstream applications like robotics, new energy vehicles, and telecommunications. These will likely continue to accelerate innovation and competitiveness in the future and may position China to deepen its influence across a wide range of strategic sectors globally.*¹⁶³

Princeton post-doctoral researcher Kyle Chan has made a similar observation—China's burgeoning strength across multiple overlapping fields positions it to capitalize on a general convergence of technologies as more complex products integrate advances in numerous fields (e.g., EVs, battery technologies, autonomous vehicles, drones, LiDAR, industrial robots, and semiconductors).¹⁶⁴ Dr. Chan highlighted how key sectors targeted in industrial policies like MIC2025 are not silos unto themselves, but are mutually reinforcing with other sectors—integrating capabilities in adjacent fields and helping establish core industrial competencies that enable further innovation in different sectors. He explained:

*China's success with its EV industry today is really the result of China's strength in a range of overlapping industries, some of which "grew up" together with China's EV industry. The flip side of this is just as important. China's focus on its EV industry is not just about selling cars. It's about using a key industrial node to push progress across a whole network of connected industries—the way that railroads were seen historically as driving broader industrial development.*¹⁶⁵

As an example, China's EV industry has built on a range of overlapping capabilities, including lithium batteries for consumer electronics, automobile manufacturing, industrial commodities refining, electric motors, AI, wireless communications, and industrial automation in manufacturing processes. In turn, the EV sector helped drive innovation across these fields and a range of other related capabilities, including energy storage, touchscreen displays, onboard software, other manufacturing processes that integrate industrial robotics, and autonomy-related technologies such as LiDAR.¹⁶⁶ The consumer drone industry has a similar production and innovation profile. Improvements in battery density, coupled with advances in composites and other materials to reduce weight, combine with development of autonomous technologies, wireless communications, and edge computing for AI integration. In turn, advances in both EVs and drones improve China's innovation capacity in sectors with overlapping technology and manufacturing profiles (e.g., autonomous vehicles). Dr. Chan visualized the numerous overlapping capabilities of Chinese firms in a Venn diagram (see Figure 1).*

*The Commission recognizes that the diagram is illustrative of a concept and is not meant to reflect a precise level of overlap between the noted industrial sectors and/or company efforts.

Figure 1: Interlocking Innovation Flywheels

Source: Kyle Chan, "China's Overlapping Tech-Industrial Ecosystems," *High Capacity*, January 22, 2025.

The Venn diagram above shows Chinese firms in the center and key technologies at the periphery, reflecting that overlapping capabilities may drive parallel advances while positioning Chinese firms to capture synergies within single companies. Notably, Chinese firms are pursuing more horizontally integrated business models in sectors with overlapping technologies, including—as discussed below—growing integration between the EV and humanoid robot markets.

Interlocking Innovation Flywheels Case Study: EVs and Humanoid Robots

An example of an IIF at work in China recently is the growing rapid efforts by Chinese EV companies to move into humanoid robots. As noted above, MIC2025 and related plans set clear goals for China to become the global leader in robotics innovation and integrated applications; more recent plans have targeted breakthroughs in core technologies now including intelligent motion planning, bionic perception, and cognitive AI.¹⁶⁷ Since at least 2023, when MIIT released a Guiding Opinion on the Innovation and Development of Humanoid Robots, China's policymakers have sought to apply core technology capabilities and China's broader technical and manufacturing competencies to develop a "global leading level" humanoid robot industry.¹⁶⁸ Explicitly connecting sectors targeted by MIC2025 and other industrial policies, MIIT stated: "Humanoid robots that integrate advanced technologies such as artificial intelligence, high-end manufacturing, and new materials are expected to become the next disruptive product after computers, smartphones, and new energy vehicles."¹⁶⁹ For their part, Chinese EV firms have broadly embraced this new state direction (Table 2).¹⁷⁰

Table 2: List of Chinese EV-Humanoid Overlap

Chinese EV-humanoid overlap	Has company debuted working prototype?	Product under development
GAC Group	Yes	GoMate Humanoid
XPeng	Yes	Iron Humanoid
Li Auto	No	CEO says the company may plan to build humanoid robots, although not currently
BYD	No	Yao Shun Yu
Xiaomi	Yes	CyberOne
Chery Automobile	Yes	Mornine
SAIC Motor	No	Is an early stage investor in several humanoid robot companies
SERES	No	Building out a humanoid robot team
Changan Auto	No	Announced plans to develop a humanoid robot by 2027
Dongfeng Motor	Yes	Partnered with UBTech Robotics to develop Walker S. and released Embodied Intelligence AI architecture with plans to enter humanoid robot market

Source: Various.¹⁷¹

The industry has capitalized on the technological and manufacturing expertise overlap between EVs and humanoid robots. Aside from software and batteries, materials, motors, and heating and liquid cooling systems originally developed for EVs can also be applied to humanoid robots (Table 3).¹⁷² In an interview with state-run *People's Daily*, Zhou Jian, CEO of UBTech Robotics, explained:

*[China's] complete industrial manufacturing system and industrial chain provide guarantees for the mass production of humanoid robots. Humanoid robots have many similarities with industrial robots, new energy vehicles and other industries in terms of supply chain. For example, resources can be shared in the supply of key components such as batteries, chips, sensors, and controllers, thereby promoting the coordinated migration of the supply chain.*¹⁷³

Industry and academic groups are also cooperating in developing interoperability standards for EVs and robotics.¹⁷⁴ Having developed supply chains that contain many overlapping components with humanoid robots, EV companies are positioned to manufacture robots more efficiently, with MIIT researcher Hu Jianya forecasting that automakers' per-unit costs could reach two-thirds the current price of units from general robotics companies.¹⁷⁵ Hu also noted that EV makers could conduct R&D in-house and respond more quickly to market changes.¹⁷⁶

In turn, Chinese media has highlighted that advances in autonomy and perception for humanoid robots “will further enhance the intelligent and technological image of automobile companies.”¹⁷⁷ Along these lines, Chinese autonomous driving firms and automakers like BYD are expanding into developing “embodied intelligence” models that power humanoid robots, taking advantage of the overlap with autonomy.¹⁷⁸ Other companies are mimicking BYD, with rival Xpeng developing its own semiconductors as the “brain” for both EVs and its in-house humanoids.¹⁷⁹ Even Xiaomi, a company known primarily for smartphones and smart devices until it entered the EV market last year, is working on developing a humanoid robot.¹⁸⁰

Table 3: Illustrative List of Shared Components between EVs and Humanoid Robots

Components and Materials	Used in Tesla Optimus	Used by Chinese EV-Humanoid Companies
Rare earth magnets	Yes	Yes
Harmonic systems	Yes	Unclear
Semiconductors	Yes	Yes
Advanced Driving Assistance System (ADAS) software	Yes	Yes
Actuators	Yes	Yes
Thermal management	Yes	Yes
Cameras	Yes	Yes
Batteries	Yes	Yes

Source: Various.¹⁸¹

Ironically, the excess capacity caused by the distortions of China’s industrial policies may help accelerate its ability to capitalize on interlocking innovation flywheels. The expansion of many EV companies into humanoid robots may be driven in part by the fierce competition in their own industry due to the massive oversupply caused by years of government support, which is severely cutting into pricing and profitability.¹⁸² In an interview with Chinese tech-focused media outlet 36kr, MIIT official Liu Xingliang noted that China’s EV market was “approaching saturation,” and humanoid robots offered “strong growth potential” for EV makers.¹⁸³

China’s Efforts to Dominate the Bio-Economy of the Future

Commercializing Scientific Discoveries in Synthetic Biology

In synthetic biology, China’s investments spanning from foundational science to state-of-the-art biomanufacturing facilities are creating an end-to-end innovation pipeline that positions it to dominate the field. This comprehensive approach—from basic, foundational research through laboratory infrastructure to specialized biomanufacturing—enhances China’s ability to translate scientific discoveries into production at scale. As with other sectors, China is well

positioned to be a leader in synthetic biology owing to its persistent policy support, sustained investments in research infrastructure, spillover benefits from innovation and capacity in adjacent fields (such as biopharmaceuticals and medical devices), and vertical integration of supporting supply chains. This combination is leading to a future in which the U.S. and global healthcare systems may depend on China for access to the best pharmaceuticals, biotechnology innovations, and most sophisticated equipment.

In its current form, synthetic biology uses engineering principles to build or modify novel or existing biological systems for desired purposes. Present-day examples include gene synthesis (e.g., developing mRNA vaccines from DNA sequences), gene editing (e.g., CRISPR technologies), and protein engineering (e.g., spider silk for textile and medical uses). As a general-purpose technology, synthetic biology has the potential to revolutionize multiple sectors simultaneously, making it a critical arena for technological competition.

Beyond pharmaceuticals, synthetic biology promises to be a critical enabler in agriculture and industrial manufacturing. Chinese researchers are applying synthetic biology to develop drought-resistant and high-yield crops, engineer lab-grown proteins to replace traditional animal agriculture, and create bio-based materials with properties that surpass petroleum-derived plastics or metals. These bio-materials—from spider-silk-strength fibers that could one day be used in aerospace components to biodegradable packaging for consumer goods—illustrate how synthetic biology could reshape entire industrial supply chains.¹⁸⁴ As such applications are developed and scaled, they could expand China's influence beyond global healthcare markets into food security, climate mitigation, and next-generation manufacturing, magnifying the strategic risk.

Synthetic biology research also has clear dual-use potential with direct military applications. These include performance enhancement for service members; rapid production of vaccines or medical countermeasures for deployed forces; forward deployed food, fuel, and energetics; and creation of bio-based materials for advanced military equipment. Advances in these areas could quickly be adapted from civilian research into capabilities that enhance the People's Liberation Army's operational effectiveness. As Stanford Bioengineering professor Drew Endy noted in oral testimony before the Commission, a sense of urgency and insecurity may be driving China to innovate in such applications more quickly.¹⁸⁵

Industry and government experts estimate that the bio-economy, currently worth nearly \$5 trillion, will grow significantly in the coming decades largely due to advances in synthetic biology.¹⁸⁶ Breakthroughs in biology, AI, and associated computational tools are beginning to demonstrate the potential to accelerate the development and deployment of synthetic biology at an unprecedented speed and scale. The convergence of these technologies could create winner-take-all dynamics, where early leaders can lock in lasting advantages in some applications of synthetic biology. Because progress in synthetic biology builds on prior discoveries and because China leads the world in building blocks like amino acid fermentation capacity, China's 70 percent share of global fermentation infrastructure gives it a potentially insurmountable head start in the iterative

testing required for synthetic biology breakthroughs. Multinational pharmaceutical companies, eager to reduce risks and costs in multi-year R&D processes, see a strong draw in China's state-of-the-art facilities, transferring knowledge and inadvertently cementing China's central role in global biomanufacturing. Meanwhile, Chinese scientists and lab technicians appear increasingly convinced that innovation accelerates when R&D and production are colocated, creating a virtuous cycle that further entrenches China's advantages.

China's Strategic Commitment to Synthetic Biology

China's strategic commitment to and industrial policy support for synthetic biology has deep roots, with early recognition dating back to 2006, when synthetic biology research was incorporated into the National High-Tech R&D Program (Program 863) (see Table 4). This support continued in 2010, with synthetic biology's inclusion in the National Basic Research Program (Program 973). Though MIC2025 focused primarily on biopharmaceuticals, it also emphasized "protein and polypeptide drugs with completely new structures" and called for increased R&D support for bioengineering.¹⁸⁷ More importantly, MIC2025's focus on biotechnology systematically helped China's synthetic biology sector through its biotech clustering efforts, talent cultivation, infrastructure development, manufacturing capacity building, and coordinated research across upstream and downstream sectors. This decade-long cultivation has positioned China to dominate not just individual components but potentially the entire synthetic biology value chain.

Synthetic Biology Clustering: Shanghai's Zhangjiang Hi-Tech Park

One prominent success of China's industrial policy efforts to promote knowledge spillovers and agglomeration externalities is Shanghai's Zhangjiang Hi-Tech Park, which has become an international hub for the biopharmaceutical industry. It houses China's cutting-edge Shanghai Synthetic Biology Innovation Center, established in 2023 with the explicit aim to create a global talent network that draws in foreign expertise while fostering international collaboration on China's terms.¹⁸⁸ University research centers, such as Shanghai Jiao Tong University's Zhangjiang Science Park School of Life Sciences and Biotechnology, offer "a world-class R&D base."¹⁸⁹ More than 1,000 biotech firms have already established their operations in the hub, including U.S.-based Danaher's life sciences affiliate division Cytiva, which trains 2,000 technical and research staff annually, effectively transferring U.S. knowhow to Chinese workers.¹⁹⁰ Biotech incubator ATLANT Innovation Center is also located in the park. It raised RMB 200 million (\$27.8 million) to incubate more than 100 biotech startups and provided R&D facilities for large companies such as Mabwell and Grit Therapeutics.¹⁹¹ This concentration of resources and talent in a single location exemplifies how China's strategic clustering approach creates gravitational pull that makes it increasingly difficult for global biotech firms to operate without a Chinese presence.

Between 2018 and 2023, synthetic biology technology was explicitly featured in several industrial policy plans of the Ministry of Science and Technology, the National Development and Reform Commission, and MIIT, including the 2022 14th Five-Year Plan for the Bio-Economy (see Table 4). These coordinated efforts produced a synthetic biology innovation center and accompanying regulatory frameworks; national scientific and technological programs focused on making breakthroughs in pharmaceutical, agricultural, and new material applications of synthetic biology; a protein data library; and support for technologies to accelerate biosynthesis.¹⁹² In 2023, the Ministry of Commerce placed synthetic biology technology such as human cell cloning and gene editing on the revised Catalogue of Technologies Prohibited and Restricted from Export, a signal that the government believes China has gained an edge in the technology.* Foreign law firms have advised that the restrictions may hinder the ability of firms operating in China from conducting R&D and biomanufacturing overseas and create complications in licensing technologies developed in China to overseas firms.¹⁹³ Taken together, these developments show that within 17 years of targeting the sector for policy support, China's accelerating, whole-of-government approach is positioning it to become dominant in frontier synthetic biology technologies.

As a result of this systematic government prioritization, China has made massive investments in building a pipeline of synthetic biology talent and education.¹⁹⁴ In 2023, China's government funding for research related to synthetic biology likely exceeded RMB 20 billion (\$2.8 billion), according to estimates from Berlin-based think tank MERICS.¹⁹⁵ Particularly, research in life sciences and medicine sponsored by China's National Natural Science Foundation of China amounted to RMB 8.5 billion (\$1.2 billion), and National Key R&D projects in fields such as synthetic biology, biomacromolecules, and microbiomes likely reached a similar amount, according to the same estimates.¹⁹⁶ Most strategically, Chinese officials are systematically elevating the standing of synthetic biology in top science, technology, engineering, and mathematics (STEM) universities. In 2025, the country's first dedicated synthetic biology and biotechnology school at a "double first class" university was established at Tianjin University, a top Chinese university that is also home to the State Key Lab for Synthetic Biology.¹⁹⁷ This institutionalization of synthetic biology education will help China produce thousands of specialized graduates annually, creating a talent pipeline that will be difficult for other nations to match.

*The technology Export Catalogue divides technologies into three categories, each subject to a different level of state oversight. First, technologies not listed in the Catalogue may be exported with minimal friction, requiring only the filing of relevant export contracts with the Ministry of Commerce (MOFCOM). Second, technologies designated as "restricted" may only be exported with a license issued by MOFCOM in advance. Third, a smaller set of technologies is outright prohibited from export. As of July 2025, the Catalogue includes 23 technologies that cannot be exported under any circumstances and 109 that require an export license prior to any cross-border transfer. These restrictions appear to relate specifically to genetic engineering. China's Ministry of Commerce and Ministry of Science and Technology, "Chinese Catalogue of Technologies Prohibited or Restricted from Export [July 2025]," *Center for Security and Emerging Technology*, July 15, 2025; China's Ministry of Commerce and Ministry of Science and Technology, "Chinese Catalogue of Technologies Prohibited or Restricted from Export," *Center for Security and Emerging Technology*, December 21, 2023.

Table 4: China's Policy Support for Synthetic Biology

Year	Agency	Policy	Detail	Strategic Significance
2006	Ministry of Science and Technology	National High-Tech R&D Program (Program 863)	First incorporation of synthetic biology into national research agenda	Foundational commitment—17 years before export restrictions
2010	Ministry of Science and Technology	National Basic Research Program (Program 973)	Expanded basic research support for synthetic biology	Deepened investment in fundamental science
2018	Ministry of Science and Technology	The 13th Five-Year Plan	Named synthetic biology as one among the seven frontier technologies	Elevated to top-tier strategic priority
2020	National Development and Reform Commission; Ministry of Science and Technology	Guiding Opinions on Expanding Investment in Emerging Industries, Cultivating and Strengthening New Growth Areas	Support the construction of a synthetic biology technical innovation center, promote biotechnology development	First dedicated innovation center—infrastructure commitment
2021	National Development and Reform Commission	Notice on the Implementation Plan for Promoting the High-Quality Development of the API Industry	Accelerate development and application of advanced technologies such as synthetic biology and enzyme engineering	Links synthetic biology to pharmaceutical dominance
2022	National Development and Reform Commission	The 14th Five-Year Plan for Bio-Economic Development	Emphasize synthetic biology as the new driving force for China's future economic transformation	Positions synthetic biology as economic game changer
2023	Ministry of Industry and Information Technology	Three-Year Action Plan to Accelerate the Innovation and Development of Non-Food Bio-Based Materials	Create a protein data library and accelerate technologies to support biosynthesis	Targets industrial applications beyond pharma
2023	Ministry of Commerce; Ministry of Science and Technology	Catalogue of Technologies Prohibited and Restricted from Export	Place “synthetic biology technology” on the revised Catalogue of Technologies Prohibited and Restricted from Export	China now restricts technology it once sought from abroad

Source: Various.¹⁹⁸

Global Leading Synthetic Biology Position from China's Industrial Policy

China's efforts at synthetic biology leadership have achieved important successes. Between 2019 and 2023, China produced nearly 60 percent of highly cited synthetic biology academic papers worldwide.* China is also systematically attracting foreign-trained talent. A striking example is Anping Zeng, a member of the German National Academy of Science and Engineering and one of the first scientists to apply protein-based engineering to develop industrial bioprocesses for amino acids.¹⁹⁹ In 2022, he left his position at University of Hamburg to return to China as founding director at Westlake Center for Synthetic Biology and Integrated Bioengineering in Hangzhou, leading research on industrial synthetic biology and integrating basic and engineering research for industrial applications.²⁰⁰ While an imperfect metric given known problems with the quality of China's patents, China has seen significant patenting activity in synthetic biology. Between 2010 and 2020, Chinese entities filed over 30,000 synthetic biology patents, more than twice the number of U.S. filings.²⁰¹

China's industrial capacity in synthetic biology is the most significant sign of its progress. The 13th Five-Year Plan called for "development of bulk fermentation products such as amino acids and vitamins."²⁰² Amino acids are the building blocks of a variety of bio-economy products—from aspartame in diet sodas to insulin for diabetics, from MSG in food to antibiotics that save lives, from animal feed critical to protein production to the mRNA vaccines that ended the pandemic.²⁰³ China's state-led efforts drove China's global-leading fermentation infrastructure. With annual output exceeding 30 million tons, China's fermentation capacity represents 70 percent of global output.[†]²⁰⁴ In some ways, fermentation capacity is to synthetic biology what semiconductor fabs are to computing; China's control over the overwhelming majority of global capacity provides it leverage over the U.S. biotech industry and positions it to lead in the future.

Background: Fermentation and Production of Amino Acids in Synthetic Biology

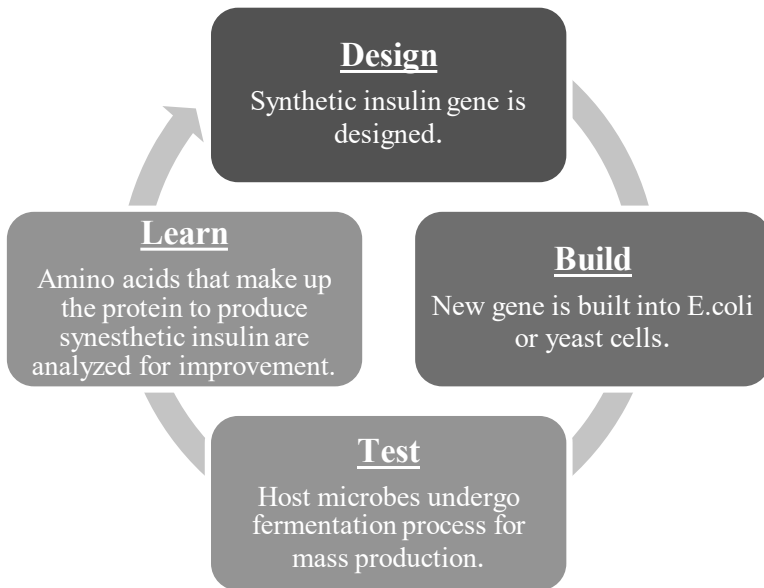
Fermentation, one of humanity's oldest technologies crucial to making wine, bread, beer, and cheese, has become critical to synthetic biology as the core part of the iterative "design-build-test-learn" (DBTL) cycle. Scientists design synthetic biological systems, build them into living cells, test their performance, and

*Research output is one measure of innovation. The methodologies used to count research papers can vary and have their values and limitations. The paper fraction allocation methodology accounts for individual researchers, signaling individuals who go on to win Nobel Prizes, etc., but it can overcount Chinese papers if there is an exceptionally large volume of Chinese researchers as authors and if there is a higher tendency of in-country citation. On the other hand, the methodology that assigns full credit to each country with an author-affiliated research institution accounts for the large volume of collaborative papers but can overlook the number of Chinese researchers contributing to the research. This statistic uses the former fraction allocation methodology. "How is China Performing Against United States in Synthetic Biology," *Australia Strategic Policy Institute*, accessed June 13, 2025.

†It is worth noting, though, that key fermentation equipment, such as stirring probes, sensors, and temperature regulators are dominated by foreign companies. Wei Luo et al., "Synthetic Biology Industry in China: Current State and Future Prospects," *Synthetic Biology and Engineering* (2023); "Global Fermenter Market Size to Worth USD 3.92 Billion by 2033: Market Insight Report," *Spherical Insights*, April 2025.

Background: Fermentation and Production of Amino Acids in Synthetic Biology—*Continued*

learn from results to refine future designs.²⁰⁵ Critically, fermentation is now the most promising process to produce amino acids with maximum yield and productivity.²⁰⁶ Researchers use fermentation to test whether engineered biological systems inserted into organisms can grow and perform the desired function at scale for large-volume manufacturing. In the learning phase, researchers study the resulting amino acids to understand interactions between components and variations in experimental setups for future improvements. Without access to fermentation capacity, many synthetic biology innovations cannot move from laboratory to commercial reality. This is precisely why China's dominance in global fermentation infrastructure represents a strategic choke-point—nations lacking adequate fermentation facilities will be forced to rely on China to scale their own innovations, effectively handing over their IP and future profits.



Fermentation is also essential for China's mass production of organic compounds like amino acids, organic acids, vitamins, and antibiotics.²⁰⁷ Many of these compounds are crucial building blocks for other bio-economy products. Due to its fermentation dominance, China accounts for 70 percent of the global amino acids market.²⁰⁸ China's high fermentation capacity enables innovation and production at scale, providing cost benefits that can allow Chinese firms to undercut Western competitors and dominate market segments. For example, China's synthetic biology leader Huaheng Bio's fermentation technology cuts the cost of non-essential amino acid alanine

by 50 percent over traditional enzymatic manufacturing methods, helping Huaheng account for about half of the global market share of alanine.²⁰⁹ In another case, China's Cathay Biotech's biochemical technologies have driven down costs of production, and it now supplies over 80 percent of global long chain dicarboxylic acids used in a variety of plastics and other chemical applications.²¹⁰

Given the DBTL cycle of synthetic biology, China's global leading fermentation capacity provides a significant advantage. Chinese innovators leverage this infrastructure to rapidly test synthetically designed biological systems and scale production of new synthetic biology products. Each iteration through the DBTL cycle strengthens Beijing's knowledge base, which may create cumulative advantages that compound over time. Without access to fermentation capacity, many of the most brilliant synthetic biology innovations cannot move from laboratory to commercial reality. Meanwhile, the U.S. biotechnology community views the lack of adequate fermentation capacity in the United States as a "biomanufacturing chokepoint" that is creating significant innovation backlogs.²¹¹ The lack of adequate capacity in the United States is already a chokepoint, effectively forcing U.S. biotech startups to partner with Chinese fermentation facilities, transferring their innovations and knowhow to potential competitors. The situation is analogous to the reliance of the U.S. biopharmaceutical industry on China-based contract research, development, and management organizations discussed in the Commission's *2024 Annual Report to Congress*.*

The Chinese government's support for biotechnology has not been consistently matched by China's private sector. Specific government and private-sector support for China's synthetic biology subsector is more difficult to track; investment in China's ostensibly private synthetic biology industry appears to have peaked in 2022 with RMB 2.82 billion (\$390 million) in disclosed value and 17 financing events.²¹² In 2024, these investments were down to RMB 412 million (\$57.3 million) in disclosed value and 15 financing events.²¹³ These numbers mirror the private sector investment trends in China for the broader biotechnology sector, which fell to a seven-year low of \$4.2 billion in 2024.²¹⁴ The decline could reflect China's broader economic climate, the relatively small size of China's biotech market (5 percent of the global biotech market versus 35 percent for the United States and 31 percent for the EU), indications that Beijing is looking to slow the growth of healthcare spending, and growing concern about U.S. market access.²¹⁵ Despite declining private investment, Beijing's massive public sector commitments ensure continued progress, and indeed China's synthetic biology market is growing. A Chinese industry research group projected that China's synthetic biology market will grow to RMB 12.4 billion (\$1.7 billion) in 2025, up 18 percent from RMB 10.5 billion (\$1.5 billion) in 2024.²¹⁶ Even modest growth in China's synthetic biology market, backed by unparalleled manufacturing infrastructure, threatens to lock in Chinese dominance before Western nations recognize the strategic implications.

*See U.S.-China Economic and Security Review Commission, Chapter 3, "U.S.-China Competition in Emerging Technologies," in *2024 Annual Report to Congress*, November 2024, 220.

Additionally, the declining private investment has further incentivized Chinese firms to find global partners who want to leverage China's testing advantage as a location for cheap, fast early-stage exploration across a range of pharmaceuticals.²¹⁷ Many Western labs, including in the United States, are increasingly partnering with Chinese labs to test their drugs as the value of drugs licensed worldwide from China reached \$48 billion in 2024.²¹⁸ The growing partnership between Chinese and U.S. drug manufacturers will likely continue as U.S. firms are rebuilding pipelines to offset \$200 billion in drugs losing patent protection by the end of the decade.²¹⁹

China's Blacklisting of Illumina

U.S.-based Illumina is the world leader in gene-sequencing machines and relied on China for up to 7 percent of its global sales.²²⁰ In February 2025, Chinese officials used the Unreliable Entity List* to implement a ban on imports of Illumina's gene sequencers.²²¹ China's action against Illumina not only was a retaliatory action against U.S. tariffs on China in February but also likely aimed to boost China's synthetic biology industry by driving domestic demand toward Chinese sequencing companies.²²² Illumina's rivals in China, including MGI Tech—a spinoff of BGI Genomics—immediately offered free trials on their own models and other incentives to win over Illumina's clients, accelerating a trend of increasing market share for Chinese companies in recent years.²²³

Implications for the United States

China's whole-of-nation push for technological supremacy represents a multifaceted threat to U.S. competitiveness and economic security. Sustained investment in state-of-the-art research facilities, state-backed licit and illicit acquisition of key technologies from abroad, and reduced input costs from market-distorting subsidies, vertical integration, and economies of scale all threaten eight decades of U.S. leadership and competitiveness in science and technology. The challenges become more acute as China transitions from moving up the value chain in established industries to securing first-mover advantage in emerging fields.

Chinese industrial policy has cultivated a growing number of national champions that capitalize on China's nonmarket practices to become competitive globally. In some sectors, China has pursued a tournament-style approach to industrial policy implementation, which seeks to build globally competitive firms through fierce but controlled competition in domestic markets. Once these firms enter the global market, many have both market-based advantages—such as competitive pricing and massive scale—and nonmarket advan-

*Established in 2020 and administered by China's Ministry of Commerce, the Unreliable Entity List is largely a counter-sanctions mechanism. The broad criteria for addition to the list include "national sovereignty, security, or development interests of China" and suspending normal commerce with or adopting discriminatory actions against a Chinese enterprise. Firms added to the list may be subject to various economic restrictions or fines, or their officers may be barred from travel to China. "PVH Facing the Risk of Being Placed on China's Unreliable Entities List," *Squire Patton Boggs*, October 10, 2024.

tages from a captive domestic market, subsidies, and state support that free them from normal profit constraints. **These advantages often enable Chinese firms to threaten longstanding incumbents from the United States and other advanced economies.**

The interaction between industrial policy and the market has fostered new forms of innovation that position China to gain first-mover advantage in emerging fields. **Contrary to perceptions that China cannot innovate, Chinese firms have evolved from “fast following” and “process innovation” to breakthrough innovations from interlocking innovation flywheels that rapidly integrate scientific knowledge into production, leverage innovation in adjacent fields, and coordinate innovative efforts across value chains.** In addition, China has captured crucial intermediate manufacturing processes that help keep its companies central in cutting-edge value chains, such as advanced fermentation in biotechnology.

In synthetic biology, China’s rapid scaling of bio-manufacturing gives it an advantage over the United States, as innovation and production in the synthetic biology sector are colocated. Leadership in synthetic biology technologies involves the ability to both innovate in the R&D stage and produce a successful product at scale. China’s fermentation infrastructure gives it an advantage in both steps. Moreover, China is positioning itself in synthetic biology similar to how it has successfully positioned itself in biopharmaceuticals. For example, though the United States currently leads in pharmaceutical innovation, Chinese biopharmaceutical companies such as Wuxi AppTec are so entrenched in U.S. supply chains that estimates indicate it would take eight years for U.S. companies to decouple and find alternative service providers.²²⁴ China’s lead in fermentation means that even innovation outside of China may need to rely on Chinese companies for production at scale. **This creates a strategic vulnerability: even if U.S. firms lead in innovation, America may remain dependent on China for manufacturing synthetic biology inputs and products.** And the Chinese synthetic biology industry, for the foreseeable future, will have access to the innovations and knowhow of global competitors that use their fermentation infrastructure.

China’s model of industrial policy will continue to chalk up important victories even when it is wasteful and inefficient, giving its companies an advantage when competing in open markets and against companies that are largely constrained by market principles. This premise is not fully internalized or understood within the U.S. policy system or global trade rules. **Insulating the U.S. economy from the distortions caused by China’s subsidized overcapacity, protected domestic markets, and control over key supply chain chokepoints requires significant modifications to U.S. and global economic statecraft, tools, and approaches.**

Countering China’s nonmarket policies alone is insufficient, however. **Without a redoubling of U.S. efforts to strengthen its advantages in science and technology, including bolstering the domestic manufacturing base and continuing to attract leading innovators and entrepreneurs from around the world, the United States risks falling behind to China’s whole-of-na-**

tion approach. Further, a response to China's industrial policy will be difficult if not impossible to execute effectively without increased coordination with key allies and partners, including joint efforts to pool market demand, prevent state-supported firms from exploiting unfair advantages, and enhance export controls.

Recommendations

The Commission recommends:

- See the Commission's classified recommendation annex for a recommendation and discussion relating to U.S.-China advanced technology competition.
- Congress establish as a strategic national objective that the United States build a resilient bioeconomy industrial base and unlock biology as a general-purpose technology before the end of the decade and support this objective through the following actions:
 - Resource the National Institute of Standards and Technology (NIST) to establish a Bio-Measurement Laboratory (BML). The BML should develop, support, and promulgate standards for biological measurements, materials, and models; advance measurement science and tools for biotechnology; and ensure U.S. standards are adopted globally as the foundation of the 21st-century bioeconomy.
 - Expand the U.S. Department of Energy's Loan Programs Office's (LPO) lending authority and capacity to include biotechnology projects. Recognizing that the biotechnology sector (outside of pharmaceuticals) faces a financing shortage that threatens U.S. competitiveness, Congress should authorize the LPO to provide loan guarantees and direct loans for biotechnology manufacturing, infrastructure, and commercialization projects. All of these efforts should focus on scaling, not on pilot projects. This expansion should include:
 - Explicit authority for the LPO to finance biotechnology projects under its other lending programs;
 - Appropriations to cover the upfront costs of making biotechnology loans; and
 - Faster application timelines and reduced bureaucratic requirements for biotechnology companies to obtain loans.
 - Strengthen and expand the U.S. Department of Agriculture's BioPreferred program to establish the Federal Government as an anchor customer for the bioeconomy by:
 - Establishing binding multi-year procurement commitments for biobased products across federal agencies, with priority for replacing defense and infrastructure materials currently sourced from countries of concern;
 - Expanding BioPreferred program eligibility to include state, local, and tribal governments as well as universities, enabling broader adoption of biobased products;

- Increasing appropriations for the Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program (Section 9003) loan guarantees; and
- Directing federal agencies to set quantified targets for biobased product adoption in their supply chains and report annually on progress toward reducing strategic dependencies.

The United States currently faces a future in which it depends on China for access to the most cutting-edge biotechnology innovations, sophisticated biomanufacturing equipment, and advanced biomaterials. The coordinated investments in standards development, measurement science, and deployment financing outlined above are essential to ensure the United States leads in the transformation of biology into a general-purpose technology capable of producing up to 60 percent of physical goods in the global economy by mid-century while maintaining national security, supply chain resilience, and economic competitiveness against strategic competitors.

- Congress strengthen the U.S. Department of Commerce, Bureau of Industry and Security's (BIS) ability to manage strategic competition with China in fast-moving technology sectors, such as leading-edge semiconductors used in artificial intelligence (AI) applications, and increase congressional oversight, including by:
 - Directing BIS to use existing authorities to require tracking technology for export-controlled advanced chips to detect and combat diversion to countries of concern;
 - Shifting the U.S. export control regime on advanced chips from a "sell" model to a "rent" model by mandating that any advanced chips above a certain threshold that are not designated as prohibited for export be accessible exclusively via the cloud. To do this, BIS shall create a license exception in the Export Administration Regulations for renting cloud access to export-controlled AI compute infrastructure with performance capabilities above a certain threshold to entities in countries of concern:
 - BIS shall determine the applicable compute threshold, with periodic adjustments as necessary to ensure the threshold adequately mitigates national security risks while keeping pace with technological developments and other trends; and
 - BIS shall require licensees to implement know-your-customer (KYC) identification programs and report suspicious activity proactively to the agency when entities domiciled within or controlled by countries of concern attempt to access the cloud infrastructure outside of approved licensing procedures or when approved entities use rented cloud infrastructure for suspected military or espionage purposes.
 - Directing the Administration to establish a systemic, integrated intelligence unit embedded at BIS, including analysts from the Intelligence Community, to formally integrate technical, analytic, financial, and collection expertise to improve

enforcement and to report to relevant committees of Congress outlining the additional resources, authorities, capabilities, and subject matter experts needed to anticipate and counter evasion strategies;

- Directing the agency to move all items subject to a “presumption of denial” license application review standard for export to China or a Chinese entity to a “policy of denial.” This would ensure the agency’s policy prioritizes national security in assessing export license applications for applicable items on the Commerce Control List or for technologies provided to companies on the Entity List; and
- Establishing a whistleblower incentive program for private citizens providing information on export control violations, similar to the program available to the U.S. Department of the Treasury under 31 U.S.C. §5323.

The recommendation seeks to address important needs in enhancing BIS’s capacity to enforce export controls consistent with congressional intent in the Export Control Reform Act of 2018. It complements the Commission’s economic statecraft entity recommendation in Chapter 3 for long-term strengthening of economic statecraft functions into a single entity while recognizing that implementation of such a recommendation to Congress is likely a multi-year process and BIS enforcement needs are urgent and ongoing.

- Congress establish a “Quantum First” by 2030 national goal with a focus on quantum computational advantage in three mission-critical domains—cryptography, drug discovery, and materials science. To achieve this ambitious national goal, the Commission recommends Congress should take the following actions:
 - Provide significant funding for U.S. quantum development, focused on scalable quantum computing modalities, secure communications, and post-quantum cryptography. To secure U.S. leadership, Congress should pair this funding with quantum workforce development initiatives, including expanded fellowships, talent exchange programs with allies, and dedicated curricula aligned with mission needs.
 - Prioritize modernization of enabling infrastructure, including cryogenic laboratories, quantum engineering centers, and next-generation fabrication and metrology facilities. These assets are essential to converting scientific discovery into deployable systems, and many current research environments remain under-resourced or technologically outdated.
 - Establish a Quantum Software Engineering Institute (QSEI) focused on developing the software foundations for scalable, secure, and interoperable quantum computing. The QSEI should also coordinate an open source ecosystem to accelerate application development and build a trusted quantum software supply chain. Modeled on the National Artificial Intelligence Research Institutes and National Manufacturing Institutes, the QSEI would ensure that U.S. quantum hardware is

matched by world-class software capabilities, enabling early operational advantage across science, industry, and defense.

Whoever leads in quantum (and artificial intelligence) will control the encryption of the digital economy; enable breakthroughs in materials, energy, and medicine; and gain asymmetric and likely persistent advantage in intelligence and targeting. It is imperative that the United States treat quantum not as a research silo but as a mission-critical national capability—and act accordingly.

While the United States retains world-leading research capabilities, China has mobilized state-scale investment and industrial coordination to dominate quantum systems and standards. For the purposes of this recommendation, the Commission presumes that China is actively racing to develop cryptographically relevant quantum computing capabilities and is likely concealing the location and status of its most advanced efforts. This is a domain where first-mover advantage could yield irreversible strategic consequences, particularly given the vulnerability of current global systems that rely on public key cryptography.

The Quantum First 2030 timeline is essential to ensure the United States achieves quantum leadership before any adversary can leverage these capabilities against American interests. Quantum technologies—spanning computing, sensing, and communication—will shape the future of strategic advantage.

- Congress enact legislation to promote investments that further three objectives: (1) continued U.S. leadership in advanced manufacturing and the associated workforce; (2) critical supply chain resilience; and (3) the security of U.S. critical infrastructure, including energy infrastructure. Such legislation should include support for programs and authorities to:
 - Establish an industrial finance entity oriented toward domestic investments. Its authorities should include financing, equity investments, and demand-side mechanisms like purchase guarantees and, with respect to inputs at risk because of nonmarket practices, price floors for domestic procurement. Congress should consider a board membership structure appointed by the Speaker and Minority Leader of the House of Representatives and the Majority and Minority Leaders of the Senate;
 - Reauthorize and expand, or create complementary legislation expanding, the authorities created by the CHIPS and Science Act of 2022 with respect to the three noted objectives, including:
 - Establishing funds to provide grants, loans, and loan guarantees to key strategic sectors;
 - Extending the advanced manufacturing investment tax credit to key strategic sectors;
 - Providing support to workforce development and education efforts, including the full range of skills necessary for production in the United States; and

- Funding national hubs for research and development in key strategic sectors.
- Direct and expand procurement authorities to enable the Administration to utilize the full acquisitions toolkit to address supply chain vulnerabilities and nonmarket challenges, including by:
 - Leveraging and expanding industrial mobilization authorities;
 - Adding dual sourcing requirements to acquisition plans for key inputs, such as foundational semiconductors and printed circuit boards;
 - Providing for, where appropriate, a true-up reimbursement for U.S. manufactured products in critical sectors; and
 - Requiring services like software testing and simulation to be performed by U.S. firms on U.S.-owned servers operated in the United States.
- Procurement actions and authorities should be stated with sufficient notice and lead time to allow firms to adjust necessary supply chains, and Congress should consider a multi-step process to achieve desired outcomes with limited disruption.

The United States must continue to support sustained investment in advanced manufacturing and basic and applied research to maintain technological leadership and remain on the cutting edge of innovation. The Commission notes that China is advancing in multiple domains and continues to deploy licit and illicit means to gain a manufacturing and technological edge, which includes a coordinated and well-funded industrial policy alongside nonmarket policy distortions.

- Congress direct the Secretary of Defense to establish a Government-Owned, Contractor-Operated Rapid Manufacturing Facility (GOCO RMF) focused on high-rate, reconfigurable production of airborne and maritime unmanned systems (both lethal and non-lethal), excluding major platforms such as ships and submarines.

The facility should:

- Serve as a surge-ready national asset, able to pivot between different system types based on operational need—including attritable drones, loitering munitions, autonomous surface vessels, and mission-tailored payloads;
- Leverage modular architectures and advanced manufacturing techniques—such as additive manufacturing, robotics, and digital engineering—to enable high-mix, low-volume, or high-volume production on demand;
- Retrain both U.S. Department of Defense personnel and the industrial workforce in the principles of rapid design, agile production, and iterative fielding, enabling a cultural shift away from long-cycle, perfect-on-paper procurement models;

- Be operated by a competitively selected contractor or consortium with a proven track record in agile manufacturing, rapid prototyping, and defense system integration;
- Integrate and coordinate with existing efforts—including the Defense Innovation Unit's Blue Manufacturing Initiative, the Manufacturing Innovation Institutes, and Defense Advanced Research Projects Agency (DARPA) transition partners—while serving as the unifying hub for defense-relevant production at speed; and
- Prioritize the production of systems that can be fielded within 12 to 24 months, using iterative deployment and feedback to improve successive generations rather than deferring capability in pursuit of flawless specifications.

In the event of conflict with China, the United States would face an adversary with an industrial base far exceeding its capacity, efficiency, and adaptability, and would confront modes of warfare that leverage China's industrial strengths and emerging capabilities in autonomy and embodied intelligence. The GOCO RMF represents an initial effort to maintain preparedness and deterrence while establishing a model for defense procurement that would better position the military services to match and exceed the pacing challenge from the People's Liberation Army.

- Congress recognize that autonomous systems—including humanoid robots, industrial automation, and unmanned systems—represent the physical embodiment of artificial intelligence and a critical domain where the People's Republic of China is rapidly advancing. To address the challenges from China's development and deployment of autonomous systems, Congress should direct the President to establish an Interagency Task Force on Autonomous Systems, chaired by the National Security Advisor, to coordinate federal efforts and report to Congress within 180 days with specific implementation plans requiring:
 - The U.S. Department of Defense to establish a Robotics and Automation Task Force with authority to rapidly prototype and deploy autonomous systems across military logistics, maintenance, security, reconnaissance, and combat operations;
 - The U.S. Department of Commerce to investigate Chinese robotics dumping under applicable trade remedy laws, lead international standards development, and expand export controls on advanced autonomous technologies to China;
 - The U.S. Department of Homeland Security to assess vulnerabilities from Chinese-made autonomous systems in U.S. critical infrastructure and establish mandatory cybersecurity standards;
 - The U.S. Department of Labor to launch workforce retraining programs and robotics technician certifications for workers displaced by automation;
 - The U.S. Departments of Transportation, Energy, Agriculture, and Health and Human Services to accelerate regulatory approvals for autonomous vehicles, infrastructure inspection

systems, precision agriculture equipment, and medical robotics;

- The U.S. Department of the Treasury to expand Committee on Foreign Investment in the United States (CFIUS) review of all Chinese investment in U.S. robotics companies and impose sanctions on Chinese robotics firms supporting the People's Liberation Army; and
- The U.S. Department of State to counter Chinese robotics exports to developing countries and lead allied coordination on autonomous weapons arms control.

China is deploying autonomous systems at scale across its economy and military while the United States remains mired in pilot programs and bureaucratic delays. These systems will transform civilian life, manufacturing, and warfare faster than current U.S. policy anticipates. Without immediate and decisive action across all departments and agencies, the United States will cede a strategic advantage that may prove impossible to recover.

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