JANUARY 2026

Tech Edge

A Living Playbook for America's Technology Long Game

A Report of the CSIS Economic Security and Technology Department

CSIS | CENTER FOR STRATEGIC & INTERNATIONAL STUDIES

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Center for Strategic & International Studies
1616 Rhode Island Avenue, NW
Washington, DC 20036
202-887-0200 | www.csis.org

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This report represents a landmark initiative by the CSIS Economic Security and Technology Department (EST), establishing the analytical framework for ongoing deep-dive analyses of the United States' strategic technology sectors. Prepared under the overall leadership of EST President Navin Girishankar and with the support and guidance of CSIS CEO Dr. John Hamre, the report synthesizes the collective expertise of EST's program directors and senior scholars.

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Foreword

The defense policy world has used “net assessments” for over five decades–a technique for systematically assessing the strengths and weaknesses of an opponent objectively compared to our own. It has been a vital tool for strategic planning and one that should be adapted and applied to the biggest economic security issues of the day, in particular the global technology competition between the United States and China.

Last year, I asked Navin Girishankar, who leads CSIS’s Economic Security and Technology (EST) Department, if he could undertake a net assessment of China and the United States on key technologies. It was a formidable task. Assessing competing economic and technology systems is far more complicated than military net assessments. It requires new frameworks and methods for evaluating strengths and vulnerabilities across very different types of technologies, including semiconductors, rare earth elements, and machine tools. This task required the full breadth and depth of expertise across EST, as well as extensive consultation with policymakers, business leaders, and subject-matter experts to comprehend the sweep of such an assignment.

The result was the flagship Tech Edge report, which provides a foundation for ecosystem assessments and rolling deep-dives in technologies that matter for economic security and national competitiveness. Most technology assessments provide static snapshots–counting patents, capabilities, or market shares at a moment in time. This report does something different: It provides a dynamic picture of the underlying drivers of innovation and diffusion that determine technology leadership. It also shows that different types of technologies require different ecosystem strengths, and that sustained advantage comes from building dexterity across multiple technologies–not merely dominance in a single domain.

This first publication launches a multiyear effort to continuously assess the technology competition between the United States and China as it evolves. My hearty congratulations to the EST team for this milestone product–one that establishes technology leadership and its role in economic security as a central pillar of CSIS’s strategic analysis.

Dr. John Hamre
CEO and President, CSIS

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Executive Summary

China is often portrayed as either unstoppable—dominating electric vehicles (EVs), batteries, and solar panels—or lacking the creativity to push the technological frontier. The United States is either celebrated as the unquestioned AI leader or criticized for losing its manufacturing base and becoming dangerously dependent on rivals. The reality is more complex—and more instructive.

In 2025, China made artificial intelligence (AI) progress under chip constraints, achieved breakthroughs in robotics and quantum computing, and weaponized its control of rare earth processing, yet it still cannot produce a certified jet engine or compete in high-end machine tools. The United States controls 90 percent of AI chip markets and produces far more advanced AI models than China, yet it has lost much of the manufacturing capacity needed to build at scale and depends on rivals for critical materials.

These patterns cannot just be explained by looking at research and development (R&D) budgets or patent counts. The answer is technological dexterity—the ability to build strengths across different technology types, where advantages in one domain compound advantages in others. AI chips enable AI models, rare earth processing enables chip manufacturing, and machine tools enable precision aerospace components. These technologies reinforce each other, but only when the right ecosystems support them.

The urgency is real: China has been playing the long game for decades—systematically building processing capacity in rare earths, scaling manufacturing ecosystems, and investing in the "missing middle" between lab and market—while the United States has too often lost focus on the ecosystem foundations that make technological leadership durable. Success depends on whether America can rebuild these capabilities faster than China continues compounding its advantages.

Technological Dexterity Is the Strategic Imperative

Existing analyses benchmark technology capabilities at a moment in time—counting patents, models, or market shares. This report does something different: It identifies the underlying ecosystem drivers that determine who leads over time.

Technology leadership flows from ecosystems, not individual breakthroughs. Ecosystems are the dynamic combinations of firms, researchers, institutions, policies, and allied networks that turn lab discoveries into factory output and individual capabilities into networked advantages deployed at speed and scale. The report identifies four building blocks of ecosystem strength and uses them to identify the underlying drivers of U.S. and Chinese technology competitiveness:

1. **Economy-wide fundamentals**, such as macro stability, rule of law, and factor markets
2. **Technology-specific enablers**, such as R&D infrastructure, IP rights, standards, and workforce and talent pipelines
3. **Ecosystem governance**, such as public-private coordination and adaptive regulation
4. **Enterprise strategies**, such as innovation cycles, production networks, and intra-firm linkages

The report also identifies four distinct technology types based on two dimensions: breadth of application and production complexity. Achieving technological dexterity—building ecosystem strengths across multiple technology types—is the strategic imperative for the United States:

1. **Stack technologies**, such as AI and advanced chips, which require deep capital markets, collaborative research networks, and platform orchestration
2. **Precision technologies**, such as jet engines and lithography, which demand decades-long partnerships and gold-standard certification regimes
3. **Production technologies**, such as high-end machine tools, which need patient capital and continuous vocational training
4. **Base technologies**, such as rare earth elements (REEs) and batteries, as well as steel and aluminum, which require coordinated supply chains and processing infrastructure

The report compares U.S. and Chinese ecosystem capabilities in one illustrative technology from each category: AI, jet engines, machine tools and rare earth elements. It shows that each of these technology types requires different combinations of ecosystem building blocks.

Technology leadership flows from ecosystems, not individual breakthroughs.

Where America Leads, Where It Lags

The United States leads in Stack technologies–controlling 90 percent of AI accelerator markets and producing 40 notable models versus China's 15–and it leads in Precision technologies like jet engines, where decades-long moats create formidable barriers for new market entrants.[1] Despite sustained prioritization by Beijing, China still has no certified commercial jet engine in flight.

But China dominates Base technologies–processing 90 percent of rare earths and producing more steel than the rest of the world combined.[2] On Production technologies like machine tools, the United States has lost historical advantages, while China also remains unable to enter high-end tiers, where the European Union and Japan lead through dense supplier networks and continuous vocational talent cultivation.

Across technology types, the United States excels at frontier research but struggles with the capital-intensive engineering, testing, and scaling phase between lab and market–ceding learning curves to competitors who invest in this "missing middle." America's advantages rest on foundations that China struggles to match: open collaboration, institutional trust, global talent attraction, and capacity to orchestrate complex partnerships with allies. But vulnerabilities compound. America invents, but diffusion lags–limiting the payoff from its Stack leadership.[3] China dominates Base technologies thanks to its use of mercantile tools that have eroded Western capacity.

Ecosystem Building Blocks: No Absolute Advantages

Economy Wide Fundamentals (World average: 50)						
United States: 73 ↑			China: 55 ↑			
Building blocks / Technology	**Tech-specific Enablers**		**Ecosystem Governance**		**Enterprise Strategies**	
	U.S.	China	U.S.	China	U.S.	China
Stack AI stack	Dominant ↑	Competitive ↑	Advanced →	Competitive →	Advanced ↑	Advanced ↑
Precision Jet engines	Advanced →	Lagging ↑	Competitive →	Emerging ↑	Advanced ↓	Lagging ↑
Production Machine tools	Competitive →	Competitive ↑	Emerging →	Emerging ↑	Emerging ↓	Emerging →
Base Rare earths	Emerging ↑	Dominant →	Competitive ↑	Dominant →	Emerging →	Advanced →

Trend of indicators: ↑ Improving → Stable ↓ Deteriorating

Qualitative scale:

Dominant | Advanced | Competitive | Emerging | Lagging

A Strategic Bind—And How America Can Break It

America is in a strategic bind: China deploys mercantile and malign tools, including below-cost dumping that bankrupts Western competitors, forced technology transfer, coercive licensing, predatory investment, and patient state capital that can tolerate prolonged periods of losses to capture entire supply chains. It is also producing genuine innovations—including world-first inventions—with increasing frequency. Meanwhile, America relies primarily on historical strengths—such as capital markets, universities, and the rule of law—without adequate tools to counter China's practices. Export controls and tariffs address symptoms but cannot substitute for building domestic and allied capacity.

The risks compound *daily*. Base technologies enable Stack technologies—without secure critical minerals inputs, chip design advantages become vulnerable to supply disruption. Production technologies determine scaling capacity—without machine tools, America cannot scale Stack or Precision technologies at home. China now threatens to do to Stack technologies what happened to Base technologies: capture commercialization and diffusion while America retains invention.

Breaking the bind requires building new capabilities: patient capital mechanisms where strategic necessity demands them, conduct-based trade tools that counter dumping and coercion without broad protectionism, allied coordination that pools resources and shares burdens, and institutional capacity to execute multiyear strategies across political transitions.

A Living Playbook That Works

To meet this challenge, the United States needs three self-reinforcing strategies:

- **Playing All the Keys:** America must develop technological dexterity by securing Base inputs, strengthening Production capacity through selective reshoring and allied networks, fortifying Precision technology moats without sheltering incumbents, and compounding Stack advantages through faster scaling and diffusion. To that end, the Trump administration and Congress should focus CHIPS Act science funding on Base and Production technology gaps—directing billions in research authorization toward time-bound commercialization grand challenges, especially where Chinese mercantilism has eroded Western capacity. They should also establish a Technology Dexterity Fund that would pool funding from the Departments of Defense and Commerce, alongside private American investors, and allied and partner capital to invest jointly in U.S. technology capabilities—sharing costs and deepening coordination that China cannot penetrate. The Defense Production Act should be deployed for Base technologies like critical minerals where patient capital requires government de-risking.
- **Achieving Speed and Scale:** The United States should move at the speed and scale that competition demands. It should impose permitting shot-clocks with enforcement teeth—rapidly cutting U.S. timelines for mining and infrastructure projects from decades to years, from years to months. It needs to break commercialization bottlenecks, where innovations die between lab and factory. The Department of Commerce should refocus Manufacturing

USA and similar programs on end-to-end pilot lines to rebuild shared engineering infrastructure and test datasets. Federal and state governments should launch sector-specific adoption accelerators targeting areas where diffusion faces the highest barriers; they should prioritize workforce development with portable credentials in desperately needed skilled trades such as electricians and technicians.

- **Defending the Network:** The United States should ramp up efforts to safeguard innovators, networks, and their innovations. It should lead and institutionalize a new multilateral regime that focuses on a broader definition of dual-use technologies. The Department of Commerce should establish dedicated "fast-action" teams specialized in high clockspeed industries and adversary reactions. The government should impose conduct-based import restrictions on below-cost dumping, coercive licensing, and predatory investment—not blanket sectoral bans. It should expand Committee on Foreign Investment in the United States (CFIUS) authorities, negotiate tech-friendly trade compacts, and create a central economic security capability for coordinating across government.

If 2025 delivered wake-up calls, 2026 demands action. Congress and the executive branch will either unify around technology leadership—or fracture into tariff wars and political skirmishes that squander the very advantages China cannot replicate. Public funding, for instance, under CHIPS and Science Act authorities, refocused today can enable targeted breakthroughs tomorrow, whereas inaction will see nascent U.S. technologies fail to scale thanks to the "missing middle." Early moves toward a Technology Dexterity Fund could build confidence among allies and supply chain partners—or the United States can wait and watch as allies hedge toward China. Permitting and related reforms at the federal and state level, enacted now, can turn infrastructure potential into deployed capacity—or projects envisioned today could languish until after 2050.

The United States must (1) "play all the keys" by developing dexterity across technology types, (2) make speed-to-scale the organizing principle for enabling infrastructure and technology diffusion, and (3) defend its networks of innovators at home and abroad against mercantile and malign threats.

The United States has rebuilt ecosystem advantages before—not through centralized direction, but coordinated action across public and private sectors. The Defense Advanced Research Project Agency's creation of the internet, the biotech revolution sparked by the Bayh-Dole Act, and rural electrification succeeded because the government, private sector, universities, and workers aligned. Americans are losing time. The question is whether the United States will reassert scientific, engineering, and manufacturing prowess, especially where it has lost ground, or whether it will continue to cede leadership.

Part I

America's Edge Depends on Technology Ecosystems

1

Moving Beyond the Myths Holding America Back

The Futures That Await Us

Throughout history, technological superiority has been the foundation of economic capacity, global influence, and national strength. From the Dutch and British maritime empires to the Allied industrial edge in World War II and America's Cold War computing advantage, this pattern has shaped the global order. Today, the full-spectrum contest between the United States and the People's Republic of China centers on "acceleration technologies": AI, quantum computing, semiconductors, biotech, energy technologies, and others still over the horizon–technologies with the greatest potential spillovers on economic growth, security, and power projection. Critically, these technologies also depend on traditional components of the industrial base like machine tools, rare earths, steel, and aluminum.

As competition over these technologies intensifies between the United States and China, starkly different futures could unfold. Which future awaits us? Which one will the United States shape?

In one future, China anchors the next economic order. Chinese chips power AI systems that are diffused globally through smart-city technologies and 6G. Chinese quantum networks secure communications, and Chinese cloud platforms dominate the digital infrastructure of the Global South and beyond. Beijing sets the rules for data, surveillance, and digital trade. State-backed firms lead in biotech and clean technologies. Control over supply chains–from batteries to rare earths–gives China coercive leverage. The yuan gains traction as a digital settlement currency, U.S. firms slide into second-tier roles, and America's workers face diminished prosperity and security. The United States grows more isolated and its alliances splinter.

In another future, the United States, with its allies and partners, reasserts global leadership. American breakthroughs in AI, quantum, and synthetic biology redefine computing, industry, and medicine. A secure semiconductor stack underpins resilient supply chains. The United States sets standards for AI governance, digital trade, and innovation norms. The American scientific research enterprise is revitalized, fueled by predictable funding of basic research, public-private investment, and new talent pipelines. America closes the gap between lab and market, revitalizing advanced manufacturing and creating well-paid middle-class jobs. Cybersecurity is treated as core infrastructure; allies invest in, rather than hedge against, U.S. leadership; and once again, American innovation drives prosperity, security, and global influence.

What Determines the Next Economic Order

These futures are not preordained. The outcome depends on the relative strengths of U.S. and Chinese *technology ecosystems*: which country builds the most dynamic combination of firms, researchers, institutions, and allied cooperation. For too long, U.S. policy has been trapped by myths that mischaracterize this competition. The costs are real—the United States has had an incoherent strategy, misallocated resources, and ceded ground where its edge should be strongest.

The challenge is that the very ecosystems the United States needs to win are under assault. The ecosystems that produce and scale technologies such as semiconductors, biotech, and quantum are deeply integrated into global value chains and vulnerable to mercantilist and malign threats, primarily from China, making them difficult to secure. U.S. policymakers must communicate the nature of this challenge and mobilize support for a national strategy in a highly polarized domestic political environment.

What Is a Technology Ecosystem?

A technology ecosystem is the dynamic combination of firms, researchers, institutions, policies, and allied networks that turn lab discoveries into factory output and individual capabilities into networked advantages deployed at speed and scale.

Myths That Need Busting

Concerns about China's technological rise span two decades. As early as 2004, the President's Council of Advisers on Science and Technology flagged weaknesses in the U.S. innovation ecosystem, and former Intel CEO Andy Grove warned that losing manufacturing and undertaking far less "learning by doing" would erode American leadership.[4] By the 2010s, policymakers were sounding alarms about the slowing pace of U.S. innovation and productivity, and congressional hearings signaled growing security concerns with respect to Chinese companies such as Huawei and ZTE.[5] The first Trump administration put U.S.-China technology competition at the center of its strategy: China's advances in AI, chips, quantum, clean technologies, and biotech, coupled with its policy of civil-military fusion, posed a distinct challenge that the United States could no longer ignore. Of particular concern were Beijing's malign actions, including cyberattacks, intellectual property (IP) theft, and mercantilist tactics that gave it leverage over the production and use of advanced technologies. The Biden administration shared this assessment.

And yet, across presidential administrations, the United States' approach to the China challenge has lacked consistency, often shifting emphasis and tools. For instance, both the first and second Trump administrations have relied on tariffs, deregulation, and tax cuts to rejuvenate American industry; by contrast, the Biden administration turned to domestic subsidies for chips and clean technologies and expanded the use of export controls on China. The sweeping 2025 Trump AI Action Plan is, among other things, a signal of the new administration's faith that deregulation, from fast-track permitting to scaling back regulatory overhead, will deliver innovation with safety, productivity with job growth, and American global dominance with enduring alliances.

The United States has had an incoherent strategy, misallocated resources, and ceded ground where its edge should be strongest.

Behind these shifts lies a deeper problem: For too long, six myths about U.S.-China technology competition have distorted the policy debate. These myths have led American leaders in business and government to misdiagnose symptoms as causes; favor knee-jerk reactions over strategic, patient policy; over-index on tools that protect existing advantages rather than build innovation capacity; and pursue strategies that are internally inconsistent:

- **Myth #1: China's edge is achieved "only" by cheating.**[6] This myth holds that for the past three decades China has pursued its national economic goals by relying on unfair, malign, and coercive practices, including currency manipulation, massive subsidization, wage suppression, IP theft, and World Trade Organization (WTO) violations. While these practices are real, the myth ignores the fact that China also demonstrates genuine innovation prowess, increasingly at the leading-edge and in breakthrough inventions. This prowess derives from investment in fundamental research, deep supply chains, rapid prototyping, learning, and manufacturing scale. The myth that China gets ahead only by cheating has led to enforcement-heavy responses from U.S. policymakers–more lawyers and fewer engineers–while China invests in innovative and productive capacities. As a result, America is on its back foot when it comes to standards-setting and scale production of technologies that generate middle-class jobs.
- **Myth #2: China is self-sufficient and catching up on its own.** This myth holds that China's ecosystem is closed to outsiders, while America's is open. It has led some to believe that America's openness and its alliances are unnecessary, or worse, a disadvantage, and that it should therefore go it alone. In reality, despite China's rhetoric and stated policies of "self-reliance," it remains heavily integrated with global networks and is actively building new alliances through deals with the European Union, East and Southeast Asia, and markets

across the Global South. Today's competition is over which country builds the broadest and deepest global ecosystem.

- **Myth #3: China's innovation system is top-down; America's is bottom-up.**[7] This myth suggests China's competitiveness derives from its national champions and government-selected "winners," while America's start-up culture wins by letting "a thousand flowers bloom." In reality, while the two economies differ radically, China's ecosystem is dynamic: It combines cutthroat competition with state-market hybrid institutions that interweave government strategic guidance, local government support, and private sector ingenuity. At the same time, the U.S. economy has experienced consolidation among entrenched incumbents, higher entry barriers, and disappearing scaling pathways for new entrants. The myth also ignores the United States' long history of successful industrial strategies: targeted R&D, public-private partnerships, procurement, and second-sourcing policy.
- **Myth #4: America can win the tech race by focusing only on technologies at the frontier, such as AI, quantum, and synthetic biology.** This myth assumes that the United States has the luxury of choosing the playing field because it will have a first-mover advantage, capable of "making the market." The myth also implicitly assumes that critical industries where the United States previously ceded its edge, such as in machine tools and metals, are a lost cause, and that it cannot or does not need to win them back. In reality, many "foundational" capabilities–including metal fabricating, electronics packaging, and even producing raw materials like rare earths–are critical to acceleration technologies and, therefore, to U.S. economic security and the viability of the American middle class. The United States cannot win on acceleration technologies without addressing the reasons why it lost these foundational capabilities.
- **Myth #5: National security risks are overblown.**[8] While the private sector must optimize revenue streams to fund future research, the myth holds that policymakers have exaggerated national security vulnerabilities, especially dual-use risks. But these risks, along with cyber threats and supply chain vulnerabilities, are grave and accelerating faster than many recognize. This myth has had real costs: U.S. cloud providers trained Chinese AI models that now power People's Liberation Army surveillance systems; the U.S. defense industrial base grew dependent on Chinese "legacy" chips; and semiconductor equipment sales accelerated Beijing's chip capabilities. Strategic leads eroded faster than export controls could adapt.
- **Myth #6: China will inevitably surpass the United States in the technology race.**[9] This myth began decades ago with a wave of projections of when China's economy would surpass the United States. This has morphed into assumptions of China's inevitable high-tech dominance. China certainly has succeeded in green technology, EVs, batteries, and drones, but these victories are often cherry-picked, ignoring China's many failures in industries that Beijing also prioritized for decades. Pessimism about America's decline ignores countless examples of successful mini-moonshots and breakthroughs across states, cities, and the private sector.

The Ecosystem Advantage

What matters now is not simply cataloging China's breakthroughs, as most analyses do, but understanding why they happen—the underlying ecosystem drivers. These drivers include the institutions, firms, business networks, policies, and alliance partners that work together to turn invention into deployment, lab breakthroughs into factory output, and individual capabilities into networked advantage. The technology competition is about which ecosystems are more effective at consistently driving innovation and diffusion, and which are more resilient to external threats.

For the United States, understanding the drivers of technological leadership, whether at home or abroad, is essential to devising a national game plan. How do China's ecosystems empower Chinese firms to gain an edge and erode American advantages in legacy chips, renewables, biotech, digital networks, and quantum communications? Is China's success purely its industrial policy or something more?

This requires an assessment of how global interdependence has given way to geoeconomic competition. Following World War II, the United States led a trading system that deepened integration through open markets and investment. However, by the 1990s, global value chains had fragmented production across borders, making U.S. innovation more dependent on foreign partners and shifting manufacturing jobs overseas. China's accession to the WTO accelerated this shift, as Beijing embedded its firms in global value chains while strategically subverting the rules, enabling its own rise through state-subsidized dumping, unfair trade practices, and IP theft. Beginning in the mid-2010s, escalating U.S.-China tensions, pandemic shocks, and the Russian invasion of Ukraine exposed the limits of interdependence. These dynamics have compelled the United States and its allies to evolve economic security tools that defend against coercion while still promoting technology leadership.

In the emerging economic order, countries that build ecosystem advantages along three axes will be positioned to win the technology long game:

- **Develop dexterity across multiple technologies.** The world is now experiencing multiple technological revolutions, in AI, chips, quantum, biotech, and clean technologies. Many of these "acceleration technologies" have the potential to generate outsized spillovers, multiplier effects, cross-domain innovations, and explosive productivity growth; they will also have a profound impact on offensive and defensive national security capabilities. Excellence across these acceleration technologies is paramount. To play the technology long-game successfully, the United States cannot afford to pick and choose. It will need to mobilize and sustain national efforts to develop capabilities across acceleration technologies such as AI, advanced chips, and quantum, as well as in supporting technologies such as critical minerals for chips, nuclear energy for AI data centers, and machine tools for advanced manufacturing.
- **Move at the speed and the scale that competition demands.** In technology competition, the leader is often determined not by who invents first, but by who moves fastest—from laboratory to factory floor and from pilot program to economy-wide adoption. China's

execution prowess in key sectors is formidable. To compete successfully, the United States requires uncommon speed in government and unparalleled scale in business. Federal agencies and state governments must identify and selectively remove key bottlenecks in permitting and procurement whenever ceding technological leadership risks national security, and private firms across industries should be incentivized to more rapidly deploy and diffuse technologies throughout the economy. Scale delivers efficiency and market dominance, but as technologies commoditize, as they have in the case of solar panels and legacy chips, the challenge shifts from innovation to supply chain resilience. America will need to ensure that commoditized technologies, in particular those that are key to acceleration technologies, remain domestic or are friendshored with allies rather than offshored to adversaries.

- **Safeguard innovators, networks, and their innovations.** Malign actions, modern mercantilism, unfair trade practices, and the exploitation of supply chain chokepoints, principally by China, have eroded the hard-earned gains of American innovators and disrupted global innovation networks. While these threats have been known for years, the United States and its allies have only recently begun to develop a tool kit to ensure autonomy in pursuing productivity-enhancing innovation. This includes promoting the resilience of supply chains critical to technology competition, preventing sensitive technologies and know-how from falling into dangerous hands, and defending the U.S. innovation system from malign actors.

What's New in the Tech Edge Report

There is considerable existing research that benchmarks U.S. and Chinese technology capabilities. These include the Australian Strategic Policy Institute's Critical Technology Tracker, the Belfer Center's Critical and Emerging Technologies Index, the Center for Security and Emerging Technology's data-driven analyses, the Information Technology and Innovation Foundation's work on China's innovation system, the report of the Council on Foreign Relations' Economic Security Taskforce; and various net assessments.[10] CSIS's approach here aims to add value to this body of work by "looking under the hood" at the underlying ecosystem drivers of technology innovation, scaling, and diffusion—and how the United States can reinforce its current advantages and build new ones.

The Tech Edge report and the wider, ongoing project offer a living playbook for America's technology long-game.

The *Tech Edge* report and the wider, ongoing project offer something new: a living playbook for America's technology long-game that evolves as the competition unfolds. To that end, this framework report will provide the basis for rolling technology modules—each one providing a stocktake of the U.S.-China competition in a major acceleration or supportive technology area such as AI, batteries, quantum, or chips. This approach identifies economy-wide and technology-specific strategies, policies, and instruments that enable the United States and its allies to achieve and sustain technological advantages. The analysis draws on engagement with the private sector, government, researchers, and investors through structured interviews, off-the-record conversations, and other convenings.

The report consists of two parts. Part I (Chapters 1–5) diagnoses the challenge and proposes a new playbook for the United States. This includes highlighting which technologies will determine economic and national security leadership, what ecosystem characteristics enable sustained advantage, how U.S. and Chinese ecosystems compare across these dimensions, and what strategic investments and partnerships can position the United States to win. Part II provides deep dives into Chinese, U.S., and select partner country ecosystems, examining how each builds technological advantage and how strategic partnerships are critical to retaining and strengthening the United States technological might.

2

Which Technologies Matter and Why?

The world is in the midst of overlapping technological revolutions that are redefining growth prospects, national security, and global influence. At their core, these revolutions are driven by acceleration technologies that yield the most economic spillovers, multiplier effects, and cross-domain synergies, and therefore deliver explosive productivity growth and decisive national security advantages. These technologies in turn depend on more traditional industries and technologies, such as mining and chemicals.

Take ChatGPT, for instance. It reached 100 million users in two months—the fastest technology adoption in history.[11] But its success rested on a complex stack. At the chip layer alone, NVIDIA graphics processing units (GPUs) are designed in California, fabricated in Taiwan using Dutch lithography machines, powered by rare earths processed in China, and cooled by cobalt mined in the Democratic Republic of Congo. These value chains reveal that acceleration technologies are interdependent with more traditional industries, but also that they matter for growth and security in different ways. Some reshape economies; others create chokepoints. Devising a winning national strategy requires understanding which technologies deliver what kinds of advantages and how to build advantages across them.

Dexterity across technologies means matching ecosystem strengths to technology types.

Understanding how technologies shape national power is only the first step. The harder challenge is building ecosystems that generate advantages in those technologies. Semiconductors and rare earths both matter strategically, but one requires collaborative platforms and elite talent clusters, while the other needs guaranteed procurement and friendshored supply chains. Likewise, AI systems and jet engines pose fundamentally different challenges. Thus, dexterity across technologies means matching ecosystem strengths to technology types.

In this report, two simple lenses do most of the work. This chapter distinguishes four types of technologies—Stack, Precision, Production, and Base. Chapter 3 identifies four building blocks of ecosystem strength: economy-wide fundamentals, technology-specific enablers, ecosystem governance, and enterprise strategies. The remainder of Part I applies these lenses to the U.S.-China competition and provides a set of policy recommendations to reinvigorate the United States' technological edge.

What Is an Acceleration Technology?

Acceleration technologies such as AI, quantum computing, semiconductors, biotech, energy technologies, and others still over the horizon are technologies with the greatest potential spillovers on economic growth, security, and power projection. Critically, these technologies also depend on traditional components of the industrial base like machine tools, rare earths, steel, and aluminum.

Making Sense of Acceleration and Supportive Technologies

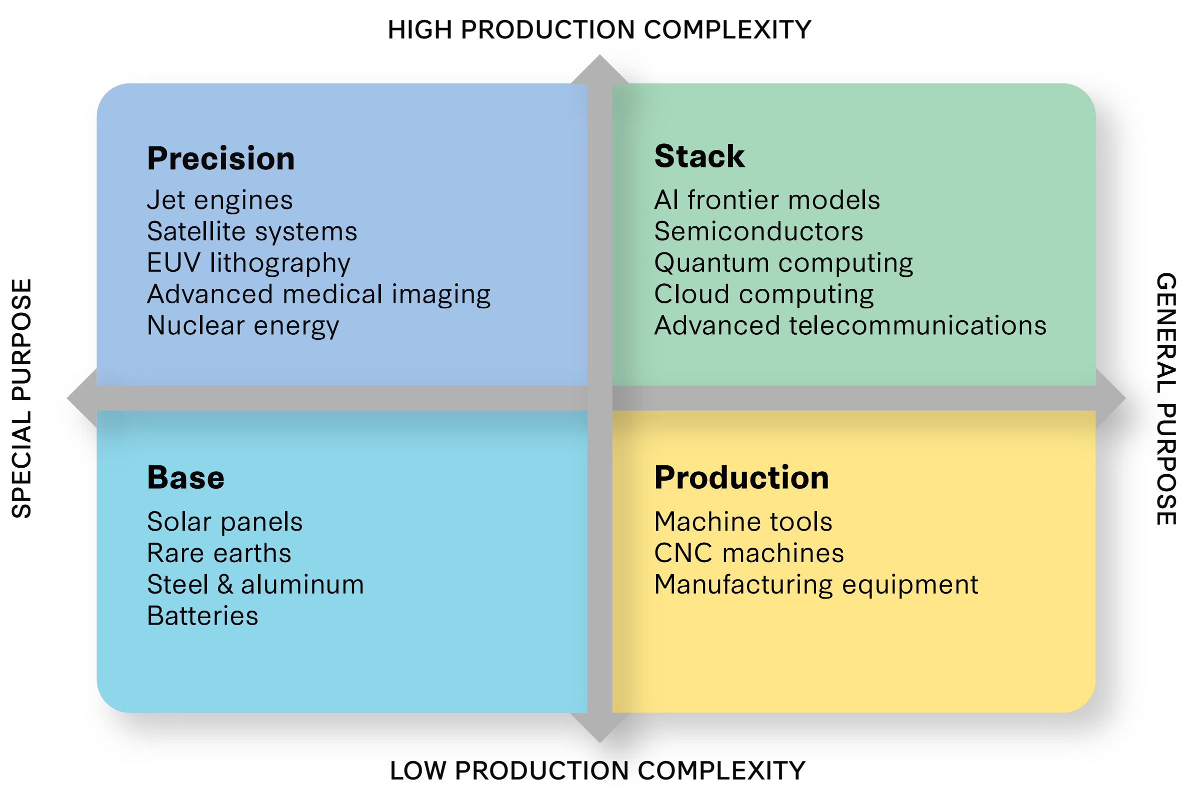
To understand the nature of technological competition, this report maps technologies along two dimensions: (1) the breadth of their application across the economy, and (2) the complexity of the production systems needed to deliver them.

On the first dimension, technologies vary in their potential uses—how many spillovers they create and how broadly they diffuse throughout the economy. Some technologies catalyze breakthroughs far beyond their original domain, while others play more specialized but still decisive roles:

- **General-purpose technologies** stand out for their breadth of application across sectors and their ability to catalyze complementary innovations that ripple through the economy. Semiconductors are the quintessential example. They underpin nearly every advanced product, including smartphones, data centers, automobiles, aircraft, medical devices, and weapons systems. Advances in chip design and fabrication ripple across the entire economy, enabling progress in AI, quantum computing, and telecommunications. AI itself is emerging as another general-purpose technology: frontier models and applications that can potentially revolutionize scientific research, robotics and advanced manufacturing, agriculture, and services such as logistics, healthcare, and finance. Other infrastructural general-purpose technologies such as next-generation telecommunications and cloud computing can spur cross-domain innovations, even while increasing exposure to cyber threats.

- **Special-purpose technologies** are narrower in scope but no less strategic. Jet engines, for instance, are not broadly diffused but are indispensable for commercial aviation and advanced fighter aircraft, and thus critical for national power projection. Solar and wind are important contributors to energy resilience and can determine the pace of decarbonization. Similarly, critical minerals like lithium, cobalt, and rare earths have limited direct spillovers but are still vital inputs to other technologies. Without rare earths, there are no permanent magnets for wind turbines or precision-guided munitions. China's dominance in REE processing illustrates how these technologies create strategic leverage. Special-purpose technologies mitigate chokepoints, sustain defense capabilities, and provide geoeconomic leverage.

Figure 2.1: Making Sense of Different Technologies



The second dimension is production complexity–how intricate production networks are and how demanding their coordination becomes. Complexity involves not just the number of inputs but the depth of inter-firm relationships and the geographic dispersion of production. Complexity has implications for scalability and fragility in the face of shocks such as pandemics, natural disasters, and economic coercion.

- **High-complexity systems** require intense coordination across many specialized suppliers and geographies. Value chains resemble dense networks often demanding trust-based collaboration and extensive interconnect standards. Advanced chips illustrate this collaboration vividly: Fabricating leading-edge chips depends on thousands of inputs, including lithography machines from the Netherlands, specialty chemicals from Japan, design software from the United States, and fabrication expertise concentrated at TSMC in Taiwan. No single firm or country controls the system; innovation emerges from global orchestration. AI frontier models similarly demand GPUs, global open-source software, hyperscale cloud infrastructure, massive energy inputs, and elite research teams across borders. These systems thrive on collaboration, but capacity concentration—such as Taiwan for chips, South Korea for memory, and Silicon Valley for design—creates vulnerability.
- **Low-complexity systems** involve simpler, more linear processes with fewer firms. REE mining and processing are far less complex than the processes leading to chips or AI, yet the concentration of these activities in China creates major vulnerabilities. Batteries and solar panels are less complex than semiconductors but more complex than mineral processing. High-end machine tools are technological marvels, requiring advanced metallurgy and precision engineering, but their production networks are less complex than chips. Importantly, simplicity does not eliminate strategic risk. Even low-complexity technologies become chokepoints if concentrated in one geography or dominated by a single actor.

The interplay of these two dimensions reveals why different technologies demand fundamentally different ecosystems—from the collaborative platforms needed for semiconductors to the guaranteed procurement required for critical minerals. A major contribution of this report is to highlight how differences in the Chinese and American ecosystems make each more (or less) competitive in particular industries.

Four Types of Technologies

Mapping the breadth of application against production complexity reveals four distinct technology types: Stack, Precision, Production, and Base, each requiring fundamentally different ecosystems. The approach developed here identifies the ecosystem drivers that enable rapid innovation, commercialization, and diffusion in each of these areas.

- **Stack Technologies:** High-complexity general-purpose technologies such as semiconductors, AI systems, and advanced telecommunications drive broad-based productivity, enable other acceleration technologies, and create high-income employment. They are "stacks" because they consist of layered systems of hardware, software, infrastructure, services, and applications, in which lower layers enable open-ended, unpredictable innovations at higher layers. Stack complexity renders these technologies the most valuable—and the most vulnerable to competition from different layers and to malign threats.

Stack technologies demand the most sophisticated ecosystems, including extensive technical standard-setting between layers, dense clusters of talent, patient capital willing to fund rapid product cycles, and broad international cooperation built on platforms. They require stable energy infrastructure, immigration pathways for elite researchers, and protection against IP theft while maintaining the open collaboration that drives breakthroughs.

- **Precision Technologies:** High-complexity special-purpose technologies, such as jet engines and highly specialized machinery like semiconductor lithography equipment, medical imagery tools, industrial gas turbines, advanced radar systems, and satellite propulsion systems do not diffuse broadly but are critical to the most high-end and advanced technologies; many are also critical to national security. They rely on long-standing partnerships across the production chain, deep expertise, tacit knowledge, trade secrets, and specialized talent pipelines that take decades to build. Dutch company ASML's monopoly on extreme ultraviolet lithography machines, built on decades of Dutch-German-American collaboration, illustrates the power of durable competitive moats.[12]

  Due to high entry costs, Precision technologies typically require sustained public-private investment such as defense contracts in aerospace, protection of trade secrets and tacit knowledge, specialized technical education programs, and targeted export controls to prevent technology leakage. They benefit from long-term relationships between partner firms, as well as between government and industry, rather than purely market-driven, price-oriented approaches.

- **Production Technologies:** Lower-complexity general-purpose technologies, such as high-end machine tools and machinery more generally, diffuse widely across the economy but involve less complex and more linear production processes compared to Stack technologies. They create substantial high-skilled employment, and they house fundamental industrial knowledge that enables new production possibilities in downstream sectors. Manufacturing leadership in Production technologies, such as computer numerical control (CNC) machines and industrial robots, determines whether countries can scale Stack technologies domestically. They are vulnerable to competition from countries that can mobilize patient capital and conduct extensive experimentation with partners.

  Production technologies benefit from tight and trusted inter-firm relationships that encourage information sharing, shopfloor learning, workforce development for skilled trades, and stable demand (including through targeted policies such as procurement mandates and subsidies). They require less cutting-edge research than Stack technologies but need resilient and stable supply chains for inputs.

- **Base Technologies:** Low-complexity special-purpose technologies, such as steel and aluminum (Box 2.1), critical minerals, basic metals and chemicals, solar panels, batteries, and standard components, are foundational building blocks for other industries, but they do not generate the extensive spillovers of general-purpose technologies. Their concentration in particular countries can create leverage and vulnerability because control over Base technologies can determine who can produce Stack, Precision, and Production technologies. China controls more than 90 percent of REE processing and 80 percent of solar panel manufacturing, demonstrating how concentration in Base technologies translates to geopolitical leverage.[13]

Base technologies require guaranteed public procurement to derisk private investment, friendshoring and supply chain diversification, patient capital willing to accept thin margins in commoditized markets, and policy recognition that market forces alone will not solve concentration risks. They often need blunt policy tools: stockpiles, processing facility subsidies, and trade protections against below-cost dumping.

Implications for a National Technology Playbook

Mapping technologies in this way offers three insights for devising a national technology playbook:

- **First, different technologies require different ecosystem strengths to incentivize and safeguard innovation.** One country may excel at Stack technologies through rapid mobilization of resources to orchestrate platforms for first-mover advantage. Another may dominate Production and Base technologies through capital mobilization at scale. Comparative advantage in one category does not translate to absolute advantage across all; each requires fundamentally different policy instruments and institutional capabilities. What makes a difference for competitiveness in AI—open collaboration and attraction of global talent—does not automatically do the same for critical minerals, where guaranteed procurement and reshoring will make a difference. Consolidating strengths in certain technologies while plugging vulnerabilities in others is how a country competes across the full technology spectrum.
- **Second, technology strengths compound on other technology strengths.** For instance, Base technologies enable Stack technologies: Without secure critical minerals, chip design advantages become vulnerable to supply disruption. Production technologies generate manufacturing learning curves that feed back into stack improvements. Scaling up battery production can drive energy density innovations for data centers. Advances in Precision technologies require simultaneous advances in Production technologies like new machine tools, which in turn generate spillovers. This framework clarifies which gaps are tolerable and which are not—for instance, losing Base technologies not only cedes that market, but can expose Stack technologies to coercion.
- **Third, any strategy must be tailored to a country's starting point.** Institutions and capabilities built over decades through culture, policy continuity, and expertise represent hard-won advantages. Strategy should leverage these existing strengths while addressing vulnerabilities through selective capacity building. Advantage comes from

tailoring instruments such as export controls, deregulation, tax credits, procurement, and immigration to each technology's ecosystem needs. That is the pathway to national strength.

The framework reveals the central strategic imperative: America must play all the keys—pursuing dexterity across acceleration technologies and the technologies that support them. Excelling in Stack technologies while ceding Base technologies to adversaries, or dominating Precision technologies while losing Production capabilities, is a recipe for failure. The technology long game requires building differentiated ecosystem strengths across all four quadrants, recognizing that advantages in one domain compound advantages in others. The question is not which technologies to prioritize, but how to build the diverse ecosystem capabilities technological competition demands.

BOX 2.1

Aluminum and Steel as Base Technologies

Aluminum and steel remain core and long-standing components of U.S. economic security policy as Base technologies supporting the automotive, energy, defense, and digital sectors. They are essential to the AI and electrification era, with chip plants and data centers depending on them for structural frames, heat dissipation, and cooling systems.

The United States has lost ground in primary production, now accounting for less than 1 percent of aluminum and 4 percent of crude steel output globally.[14] Decades of industrial decline that weakened domestic steel demand, short-term cost-cutting, slow technology adoption, and high labor and energy costs have eroded competitiveness. Meanwhile, competitors in Canada, Russia, the Middle East, and Asia have leveraged low labor costs, state-backed financing, and productivity gains to capture global market shares.[15] China, which is the world's leading producer in both, has also depressed global prices through state-subsidized overcapacity, contributing to U.S. strategic vulnerabilities.[16]

Washington has long oscillated between two approaches: indigenization and reliance on allies. Current efforts combine allied investment, federal policy, and trade measures. Nippon Steel's purchase of U.S. Steel and Hyundai Motor's Louisiana steel factory project highlight foreign investment in domestic capacity.[17] Canada, Australia, and Norway supply low-carbon metals that complement U.S. output.[18] Federal incentives under the Inflation Reduction Act and Infrastructure Law support low-carbon technologies and "Buy America" standards, while recent Section 232 tariffs and "melt and pour" rules aim to protect U.S. producers, though they risk raising costs for downstream manufacturers.[19] While earlier promotion policies fell short, the present reindustrialization agenda offers a more promising foundation for revival, with success depending on revitalizing the broader industrial base to lift domestic steel demand.

Table 2.1: U.S. Aluminum and Steel Production in Thousands of Metric Tons, 1970–2020

Aluminum						
Year	**1970**	**1980**	**1990**	**2000**	**2010**	**2020**
United States	3,607	4,654	4,048	3,700	1,720	1,000
China	130	360	850	2,600	16,800	37,000
Global	9,661	15,427	17,977	23,900	41,400	65,200

Steel						
Year	**1970**	**1980**	**1990**	**2000**	**2010**	**2020**
United States	119,000	101,000	89,726	102,000	80,500	72,700
China	18,000	37,120	66,100	128,500	637,230	1,064,767
Global	594,478	714,387	770,638	849,000	1,440,000	1,880,000

Source: U.S. Geological Survey.[20]

3

The Building Blocks of Technology Ecosystems

Taiwan fabricates 90 percent of the world's most advanced chips.[21] South Korea dominates memory semiconductors.[22] China controls more than 90 percent of REE processing.[23] The advantages these countries have established did not emerge by accident—they reflect decades of deliberate ecosystem building. Chapter 2 established which technologies matter and why. This chapter reveals how countries build the ecosystem capabilities that generate sustained advantages—and why some consistently outperform others despite access to similar resources.

Four building blocks determine ecosystem strength, each varying in importance depending on whether a country is pursuing Stack, Precision, Production, or Base technologies. These building blocks are:

1. **Economy-wide fundamentals:** The macroeconomic stability, rule of law, and factor markets that enable any innovation
2. **Technology-specific enablers:** The R&D investments, standards, IP rights, and talent pipelines tailored to particular domains, and the policies that target them
3. **Ecosystem governance:** The institutional capacity to coordinate, adapt, and respond to dynamic markets or security threats across public and private actors
4. **Enterprise capabilities:** The firm-level strategies, production networks, and resilience that convert policy support into commercial advantage

While all four building blocks matter across technologies, their relative importance varies by technology type—and understanding these differences is essential for building the right mix of capabilities.

Building Block 1: Economy-Wide Fundamentals

A stable, economy-wide framework is the bedrock of competitive technology ecosystems. Rule of law, sound macroeconomic management, and well-functioning factor markets create the enabling environment for innovation and scaling. Favorable macro-fiscal outcomes—low inflation, sustainable debt, and stable exchange rates—are underpinned by institutional safeguards, including independent central banks, capable finance ministries, and robust fiscal rules. These institutions serve as bulwarks against exogenous shocks like financial crises and pandemics. By contrast, weak property rights, volatile inflation, fiscal crises, and other forms of policy-induced uncertainty cause firms to freeze activity, including through reductions in hiring and investment that on average trigger a 1 percent decline in industrial production.[24]

Product market policies, trade and competition policies, and IP rights are essential to a pro-innovation enabling environment. Evidence from countries belonging to the Organisation for Economic Cooperation and Development (OECD) demonstrates that the policy and regulatory framework for product markets can stimulate—or undermine—innovation and firm-level productivity. Research shows that moving from a low-competition environment to an optimal level of competition is associated with a 40 percent increase in patent-weighted innovation.[25] A strong patent system safeguards against malign actions such as rampant IP theft, adversarial capital seeking equity stakes in innovative companies, and related concerns.

Factor markets that govern capital, labor, land, infrastructure, and energy are equally critical. Innovation thrives on robust capital markets that fuel technology development at every stage—from seed funding to venture capital and growth equity. For instance, a dollar of venture capital is three to four times more potent in stimulating patenting than a dollar of traditional corporate R&D.[26] Even with financial deepening, capital market pressures can prioritize short-term returns over long-horizon investments. Flexible labor markets also provide comparative advantages across future technologies and industries. Access to ample, diverse, and competitively priced energy is critical to industrial resilience and technological advancement. Energy plays a decisive role in powering AI data centers, semiconductor fabs, quantum and biotech clusters, and advanced manufacturing.[27] Cybersecurity measures must protect critical energy infrastructure and other national interest assets.

A stable, economy-wide framework is the bedrock of competitive technology ecosystems.

Economy-wide fundamentals matter across all technology types, but in different ways. For instance, Stack technologies such as AI and semiconductors depend heavily on robust capital markets and high-skilled immigration to attract global talent. Precision technologies such as jet engines benefit from strong IP protections and long-term contracting. Production technologies such as machine tools are particularly responsive to flexible labor markets and access to finance for small and medium-sized enterprises. Base technologies such as rare earths processing and steel require stable energy costs and patient capital willing to accept thin margins.

Building Block 2: Technology-Specific Enablers

Economy-wide incentives are necessary but not sufficient in today's strategic technology competition. After decades of market-first orthodoxy, concerns about stagnant productivity, fragile supply chains, and China's techno-industrial surge have triggered a rethinking of the state's role in shaping productive sectors. While debate persists on which tools—subsidies or tax credits, export restrictions or promotion, public or private R&D—are most effective, one point is clear: Geoeconomic competition cannot be won with technology-neutral policies alone. Modern ecosystems require industrial policies tailored to specific technologies, industries, and value chains.

Basic and applied research fuels breakthrough innovation. R&D excellence requires not just volume but quality, security, and commercial conversion as well. For instance, public R&D in the United States seeded breakthroughs such as the internet and mRNA vaccines, while private R&D dominates user-driven innovation. China is rivaling advanced economies in both scale and quality.[28] With rising geopolitical stakes, research security—through project enclaving and researcher clearance—has become essential to protect the discovery-to-commercialization pipeline. Engineering and testing infrastructure—pilot lines, prototyping facilities, and common test protocols—provide the capital-intensive pathway from lab to market, including the iterative failures and steep learning curves required for Stack and Precision technologies. The United States' experience exemplifies the costs of failing to invest in R&D, security, and the industrial commons. Federally funded R&D has declined as a share of GDP even as the engineering and manufacturing base has hollowed out, creating a "missing middle" between upstream research and downstream commercialization, leaving technologies stranded in the development pathway.[29]

Modern ecosystems require policies tailored to specific technologies, industries, and value chains.

Governments have revived industrial policy to build national competitiveness. Countries are deploying tools like subsidies, tax credits, procurement, and public-private collaboration with renewed urgency. Japan and Germany coinvest with firms to solve chokepoints; China's development zones mobilize resources at scale; and the United States has made similar efforts through the CHIPS and Inflation Reduction Acts and, more recently, the Investment Accelerator and acquiring equity stakes in Intel.[30] Strategic procurement—long key in aerospace and biotech—now accelerates clean energy, critical minerals, and secure digital infrastructure. These tools require capable bureaucracies, real-time industry feedback, and political will. In the era of geoeconomic competition, the greater risk is standing still.

Technical standards set the rules that ensure technologies interoperate, scale efficiently, and compete globally—and countries that shape these rules often dominate subsequent markets. Bodies like the International Organization for Standardization (ISO), International Telecommunication Union (ITU), and Institute of Electrical and Electronics Engineers (IEEE), along with niche standards-setters, define how technologies—such as 5G, EVs, and synthetic biology—achieve efficiency, interoperate, scale, and remain safe. Standards setting confers strategic benefits: early IP licensing, embedded design preferences, and downstream market control. For instance, when a company's patent becomes the industry standard in standard-setting organizations, its economic value doubles and its owners gain market leverage.[31] U.S. firms like Qualcomm have benefitted from early leadership in wireless standards. Today, China's "Standards 2035" aims to shape global rules in AI, biotech, and smart infrastructure, sometimes at the cost of global interoperability. Meanwhile, the U.S. government struggles to staff many influential standards discussions. Standards are no longer just technical details—they are levers of market power.

Advantage requires world-class talent in technology-specific domains across all skill levels. Scientists, engineers, technicians, data center operators, and skilled tradespeople all power innovation ecosystems. Building this workforce means investing across the entire talent pipeline, from foundational education and science, technology, engineering, and mathematics (STEM) programs to apprenticeships and lifelong training. Countries that systematically cultivate homegrown talent while attracting global expertise are poised to shape the innovation frontier. Without that pipeline, any technology strategy rests on a fragile foundation. The United States has long excelled in this area, fueled by world-class universities and high-skilled immigration; a single percentage point increase in the population share of immigrant college graduates increases patents per capita by between 9 and 18 percent.[32] But recent restrictions threaten to erode this edge and open the door for competitors to lure specialized U.S. talent. South Korea and Japan have sustained robust STEM pipelines, and Germany and Singapore excel in vocational models. Demographic decline in many OECD countries due to falling birth rates and aging populations risks constraining the future talent pool.

Safeguarding technology-specific incentives is essential. Threats like IP theft, supply chain infiltration, and coercive licensing can derail innovation. Protecting these incentives requires sector-specific tools, such as IP enforcement, public-private vetting, secure procurement, and calibrated export controls. These safeguards should reflect each technology's unique vulnerabilities, especially where innovation is concentrated in a handful of enterprises or tightly integrated global networks. Overdesign, however, can also stifle progress. Excessive securitization—through blanket restrictions or over-classification—can isolate ecosystems, deter top talent, and fragment collaboration. The goal is a balanced approach: one that shields critical advantages while preserving the openness and speed that innovation requires.

These enablers matter differently across technology types. Stack technologies demand cutting-edge R&D, open standards for interoperability, and elite global talent. Precision technologies depend on long-term R&D partnerships, specialized talent pipelines, and trade-secret protection. Production technologies require engineering infrastructure, vocational training, and stable procurement. Base technologies benefit from guaranteed procurement, supply chain diversification, and patient capital.

Building Block 3: Ecosystem Governance

Even the best policies fail without institutional capacity to coordinate, adapt, and deliver. Ecosystem governance—the ability for public and private actors to work together effectively—determines whether ambitious strategies translate into real capability. This requires mechanisms for public-private dialogue, interagency coordination, adaptive regulation, and crisis response. Countries with strong governance orchestrate across ministries, align industry and government priorities, and respond rapidly to disruptions. Those with weak governance suffer from bureaucratic silos, policy incoherence, and slow adaptation.

Effective ecosystem governance operates through platforms that bridge sectors. Japan's Ministry of Economy, Trade and Industry (METI) convenes industry dialogues that shape industrial strategy. The United States deploys advisory committees, consortia, and regional hubs to coordinate research and commercialization. The European Union's Important Projects of Common European Interest (IPCEI) framework pools member state resources for strategic technologies. These platforms work when they combine clear goals and mandates, adequate resources, and real authority to shape outcomes—and they fail when they become talk shops.

Adaptive regulation is equally critical. Technologies often evolve faster than regulatory frameworks, creating uncertainty that can stall investment or allow harmful practices to proliferate. Countries that update regulations in real time—balancing innovation with safety, competition, and security—enable faster commercialization. For instance, the United Kingdom's fintech regulatory sandbox enabled participating firms to see a 15 percent increase in capital raised and a 50 percent higher probability of raising funds compared to their peers, confirming that regulatory certainty directly fuels growth.[33] Singapore's regulatory sandboxes for fintech and the U.S. Food and Drug Administration's expedited approval pathways for medical devices demonstrate how thoughtful adaptation can accelerate deployment while managing risk. Countries that lag either strangle innovation with outdated rules or allow risks to accumulate unchecked.

Even the best policies fail without institutional capacity to coordinate, adapt, and deliver.

Crisis response capacity—the ability to mobilize resources rapidly under stress—separates resilient ecosystems from fragile ones. The Covid-19 pandemic, semiconductor shortages, and energy disruptions exposed weaknesses in supply chains and institutional readiness. Firms that suffered supply chain disruptions experienced a 107 percent drop in operating income growth relative to peers and an immediate 10 percent loss in shareholder value.[34] The United States deployed tools such as the Defense Production Act to expand domestic production of critical goods. China's centralized system enabled rapid industrial mobilization, but sometimes at the cost of efficiency. Going forward, ecosystems need pre-positioned authorities, stockpiles, and coordination mechanisms that activate quickly under duress. Safeguards like emergency production authorities, strategic reserves, and multilateral crisis frameworks will determine which countries weather shocks without losing technological ground.

Governance demands vary by technology type. Stack technologies require rapid coordination across multiple agencies (trade, defense, and commerce) and international standards bodies. Precision technologies need stable, long-term partnerships between government and industry. Production technologies benefit from regional coordination platforms linking manufacturers, suppliers, and workforce developers. Base technologies require crisis authorities and multilateral frameworks for supply chain resilience.

Building Block 4: Enterprise Strategies

Ultimately, technology leadership depends on enterprises–their ability to innovate, scale, collaborate, and adapt. Firms operate within the ecosystem provided by the first three building blocks, but they must also develop internal capabilities that convert opportunity into advantage. This includes mastering the full innovation cycle (research through commercialization), building resilient supply chains, forming strategic partnerships, and pivoting when markets or technologies shift.

Innovation and commercialization thrive on clustering and supply chain linkages. Enterprises succeed when embedded in dense networks–local and global–where knowledge, talent, and financing flow rapidly. Taiwan's chip ecosystem, Germany's auto clusters, and Japan's robotics sector demonstrate the power of spatial and sectoral coordination. In the United States, AI model developers depend on upstream chipmakers and downstream cloud providers, often in tight co-design loops. These relationships span borders and require trust, interoperability, and incentives to share and iterate. The geography of innovation may be global, but clustering–physically or virtually–remains a powerful amplifier of enterprise competitiveness. TSMC's success, for instance, stems not just from fabrication expertise but from its orchestration of hundreds of suppliers, equipment makers, and design partners in a tightly coordinated ecosystem that competitors struggle to replicate.

Enterprises succeed when embedded in dense networks—local and global—where knowledge, talent, and financing flow rapidly.

Enterprises face real disruption risks, such as from cyberattacks, industrial espionage, investment-based coercion, and supply chain chokepoints. These threats are not abstract. China's export controls on REEs, malign foreign investments in strategic startups, and IP theft through digital channels all pose risks to enterprise viability. Enterprises need robust internal controls, supply chain monitoring, and coordinated support from government tools like CFIUS for investment screening, the Defense Production Act for emergency mobilization, and specialized supply chain offices. Without safeguards, even the most innovative firms become vulnerable.

Strategic partnerships—between firms, across borders, and with research institutions—determine whether enterprises can access critical inputs, share risks, and scale innovations. Germany's Mittelstand firms thrive through supplier networks that share costs and knowledge. South Korean *chaebol* leverage vertical integration to control entire value chains. American tech firms increasingly form consortia (e.g., the Semiconductor Research Corporation and the U.S. AI Safety Institute Consortium) to pool R&D and shape standards. These partnerships work when built on trust, aligned incentives, and shared strategic objectives.

Enterprise capabilities translate directly into technology leadership. Stack technologies require firms that can orchestrate global platforms and rapid iteration cycles. Precision technologies depend on strategies for preserving and promoting deep tacit knowledge, multidecade talent retention, and patient capital. Production technologies need enterprises embedded in tight supplier networks with shopfloor learning cultures. Base technologies need vertically integrated firms or government-backed enterprises that can operate at lower margins for strategic reasons.

Countries that cultivate agile, connected, and secure enterprise capabilities will lead the next wave of technological transformation. This requires not just entrepreneurship but ecosystem orchestration—ensuring that the right players, policies, and protections are in place to move faster than rivals and more safely than adversaries.

Table 3.1 summarizes the four building blocks, the core elements of each, and the policy levers and safeguards that matter most across technologies. But technological advantage requires dexterity—building differentiated ecosystem strengths in each type of technology rather than one-size-fits-all capabilities. Stack technologies demand different combinations of these building blocks than Precision, Production, or Base technologies. Countries that excel in one type often struggle in others because the required capabilities differ fundamentally. Dexterity means understanding these differences and investing accordingly.

Technological advantage requires dexterity—building differentiated ecosystem strengths in each type of technology rather than one-size-fits-all capabilities.

Table 3.1: Building Blocks of National Technology Ecosystems

Building Block	Core Elements	Key Levers	Safeguards
1. Economy-Wide Fundamentals	• Macroeconomic stability • Rule of law • Factor markets	• Well-functioning central bank • Fiscal discipline • Property rights • Open product and capital markets • Energy and infrastructure access	• Central bank independence • Fiscal rules • IP rights • Cybersecurity for critical infrastructure
2. Technology-Specific Enablers	• Sector-specific policies • R&D • Standards • Labor	• Targeted subsidies and tax credits • Strategic capital and procurement • Public-private R&D • Technical standards shaping • Workforce and talent development	• IP enforcement • Export controls • Secure R&D protocols • Targeted public-private safeguards
3. Ecosystem Governance	• Institutional coordination • Responsiveness • Learning • Crisis response	• Public-private alliances • Strategic tech task forces • Adaptive regulation • Multilateral frameworks	• Crisis tools • Joint governance platforms • Strategic alliances
4. Enterprise Strategies	• Agility • Clustering • Resilience • Talent development	• Full-cycle innovation • Inter-firm networks • Value chain integration • Strategic pivoting	• Investment screening • Internal supply chain monitoring • Enterprise-level risk management

Source: CSIS Economic Security and Technology Department.

The next chapter examines how these building blocks combine across the four technology types, revealing where ecosystem strengths align with technology demands, where mismatches create vulnerabilities, and what strategies enable countries to play all the keys.

4

A Technology Balance Sheet

Where America Leads, Where It Lags, and Why

Chapters 2 and 3 introduced the technology typology and the four ecosystem building blocks; this chapter applies these concepts to assess how the United States stacks up against China. The United States dominates AI systems and jet engines. China controls rare earth processing and leads in solar manufacturing. Neither country excels across all technology types, and neither can easily replicate the other's ecosystem strengths. This chapter applies the four-quadrant framework to reveal where America leads, where it lags, and why, examining AI as a Stack technology, jet engines as a Precision technology, high-end machine tools as a Production technology, and rare earths as a Base technology.

The analysis overturns the myths about U.S.-China technology competition discussed in Chapter 1. The "hollowed-out" story of U.S. manufacturing is refuted; America retains formidable advantages in Precision technologies like jet engines, built over decades. Nor is Chinese innovation purely top-down statism or achieved through cheating; cutthroat competition among local champion firms drives genuine breakthroughs in batteries, solar, and algorithmic efficiency. And neither country can go it alone. In some industries like rare earths, market mechanisms fail without government intervention. In others like machine tools, allied networks provide capabilities neither superpower can rapidly rebuild. The country that taps global knowledge networks and engages partners and allies will be able to compound advantages others cannot match. This presents an opportunity to play to the United States' time-tested strengths.

Neither the United States nor China enjoys absolute advantages across acceleration technologies and the technologies that support them:

- The United States retains decisive advantages across a number of Stack technologies—for instance, AI systems and advanced semiconductors—where success depends on dense talent clusters, technical standards and platforms to organize the stack, access to specialized finance, and institutional and regulatory frameworks that reward risk-taking and open collaboration. China is closing the gap in AI through excellence in specific domains such as algorithmic efficiency and talent that offset its disadvantages in compute.[35]
- China dominates Base technologies such as rare earths, steel, and aluminum and is rising in select Precision technologies such as DNA sequencing and advanced medical imaging, where exceptional firms paired with local governments created systematic advantages by deploying state capital, coordinating supply chains, and implementing industrial policies.[36]
- The United States maintains formidable leads in other Precision technologies, such as jet engines, where it benefits from decades-long moats in which the United States has built on deep private and public expertise, cooperative alliances, gold-standard certification regimes, and defense partnerships.
- On Production technologies such as machine tools, the United States has lost its historical advantages. China also remains unable to enter high-end tiers, where the European Union and Japan lead through dense supplier and user networks and continuous vocational talent cultivation.
- Across technology types, the United States excels at frontier research but struggles with the capital-intensive engineering, testing, and scaling phase between lab and market, ceding learning curves to competitors who invest in this “missing middle.”

Figure 4.1: Ecosystem Building Blocks: No Absolute Advantages

Economy Wide Fundamentals (World average: 50)						
United States: 73 ↑			China: 55 ↑			
Building blocks / Tech-nology	**Tech-specific Enablers**		**Ecosystem Governance**		**Enterprise Strategies**	
	U.S.	China	U.S.	China	U.S.	China
Stack AI stack	Dominant ↑	Competitive ↑	Advanced →	Competitive →	Advanced ↑	Advanced ↑
Precision Jet engines	Advanced →	Lagging ↑	Competitive →	Emerging ↑	Advanced ↓	Lagging ↑
Production Machine tools	Competitive →	Competitive ↑	Emerging →	Emerging ↑	Emerging ↓	Emerging →
Base Rare earths	Emerging ↑	Dominant →	Competitive ↑	Dominant →	Emerging →	Advanced →

Trend of indicators: ↑ Improving → Stable ↓ Deteriorating

Qualitative scale:

Dominant | Advanced | Competitive | Emerging | Lagging

Note: Economy-wide fundamentals refer to rescaled z-scores that are a composite index of eight economy-wide indicators (see Figure 4.2) that score the United States and China relative to all countries. The economy-wide fundamental gap is 19, but due to rounding, the figure shows a gap of 18. See Appendix A for methodology.

Source: CSIS Economic Security and Technology Department. For the source of economy-wide fundamentals, see Figure 4.2.

This chapter proceeds in two parts. First, it compares economy-wide fundamentals—the macroeconomic stability, institutional quality, factor markets, and other fundamentals that enable any technology ecosystem. Second, it examines how other building blocks, including technology-specific enablers, ecosystem governance, and enterprise capabilities, operate differently across four technology types, revealing the specific mechanisms that drive U.S. leadership in Stack (AI) and Precision technologies (jet engines), China's dominance in Base technologies (rare earths), and the role of allies in vital Production technologies (machine tools).

Economy-Wide Fundamentals

Without strong economy-wide fundamentals, countries cannot develop technological dexterity. The United States retains decisive advantages in its institutional quality and openness, while China is closing the gap in infrastructure—critical to technology competitiveness. Figure 4.2 compares the United States and China to the rest of the world using a standardized index (see Appendix A for methodology). The United States' relative strengths are most pronounced in rule of law, regulatory quality, capital markets, and openness to investment. By contrast, the dominance of state-owned enterprises (SOEs) in China's energy, transportation, and banking sectors stifles competition, efficiency, and adaptability—precisely where it needs these most. For both economies, public indebtedness is a drag, although China's official figures do not capture local government liabilities, making its position worse than publicly stated.

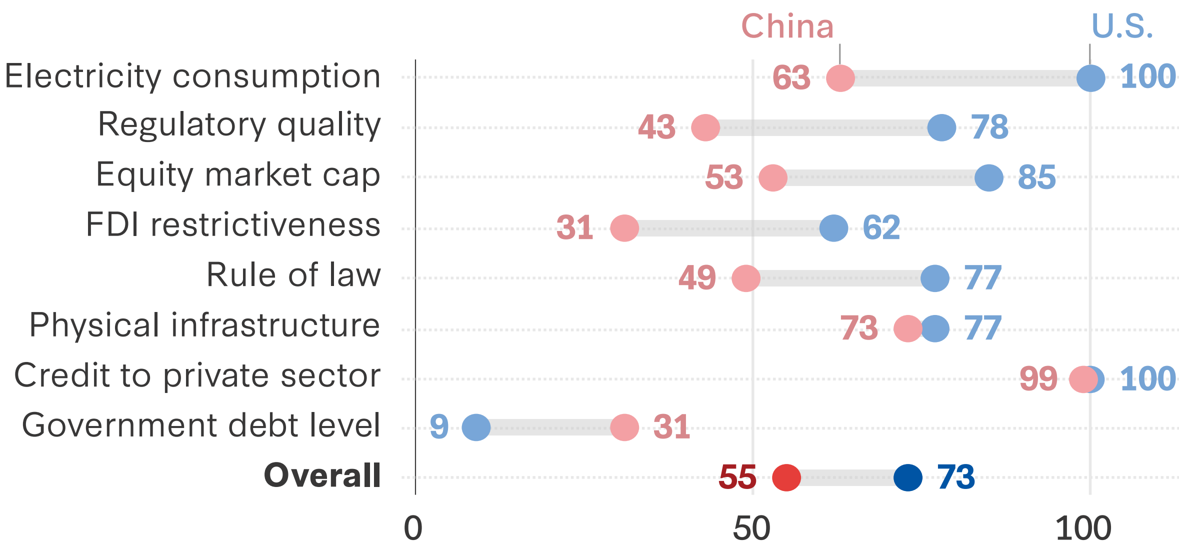
The United States' relative strengths are amplified by dollar dominance, though overvaluation creates offsetting costs. An independent central bank, deep financial markets (~$68 trillion, ~223 percent of GDP), and dollar reserve status (~58 percent of global reserves) enable U.S. technology firms to raise capital at lower costs than foreign competitors, fund long-horizon R&D without exchange rate risk, and leverage financial networks facilitating high-standards technology partnerships.[37] By contrast, China's capital controls cap renminbi internationalization and limit China's leverage of global financial networks. The "exorbitant privilege" of the dollar's reserve currency status comes with systematic overvaluation, which has contributed to industrial hollowing-out.

U.S. capital markets, with their unparalleled breadth and depth, are foundational to American innovation and far more productive at value creation than China's state-directed model.

U.S. capital markets, with their unparalleled breadth and depth, are foundational to American innovation and far more productive at value creation than China's state-directed model. However, this creates a strategic bind for U.S. firms. U.S. capital markets quickly punish firms operating with returns below their cost of capital, while Chinese state-backed firms sustain profit destruction for years without investor pressure. Across tradable sectors, U.S. manufacturing and engineering firms are squeezed between domestic investors demanding higher returns and Chinese competitors sustaining losses indefinitely. Caught in this bind, U.S. firms curtail revenue growth, squeeze supply chain profits, divest production assets, and cut employment. These pressures are compounded by an unfriendly investment tax regime and currency overvaluation that give imports an effective price discount, forcing domestic producers into margin compression. The cumulative effect: loss of production assets, supplier networks, and expertise—especially among small and mid-sized industrial suppliers—that leaves the United States unable to scale new technologies even when it invents them.

China compensates for weaknesses through centralized coordination that delivers speed and scale. The People's Bank of China lacks the autonomy of the Federal Reserve, but industrial policies hew to growth targets. State banks and hybrid state-private investment vehicles push capital into priorities where private investors hesitate, including core infrastructure and strategic industries, including nearly $676 billion into clean energy in 2023 alone, and over $100 billion into lithium for batteries between 2009 and 2019.[38] This helps explain how China has achieved parity with the United States in infrastructure and credit access, although other factors contribute as well.

Figure 4.2: Economy-Wide Fundamentals



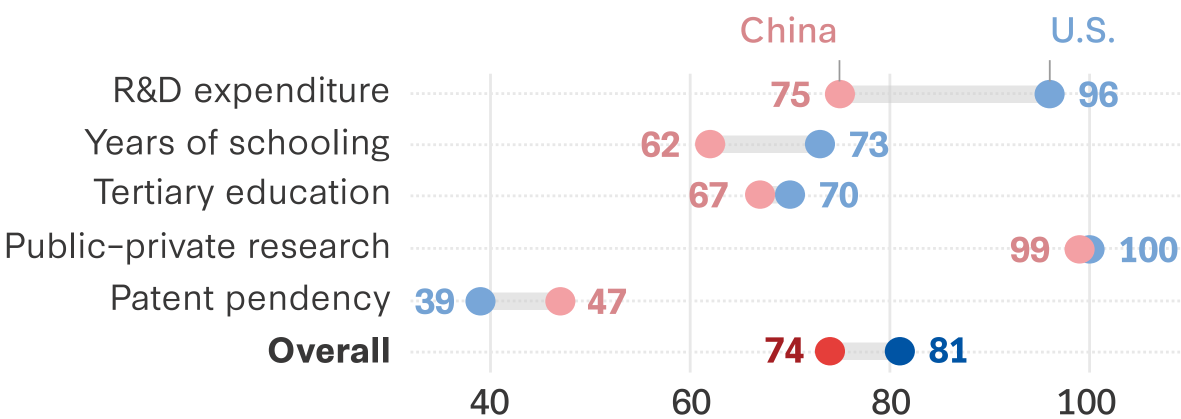
Note: This chart displays rescaled z-scores of select indicators (global average=50; standard deviation=20). All indicators refer to 2023 except for electricity consumption (2022), equity market cap (2022), and government debt level (2024). The overall economy-wide fundamentals gap is 19, but due to rounding, the figure displays a gap of 18. Original units: Electricity consumption (kWh per capita); regulatory quality (World Bank index); equity market cap (% of GDP); FDI restrictiveness (OECD index); rule of law (World Bank index); physical infrastructure (World Bank index); credit to private sector (domestic credit as % of GDP); government debt level (% of GDP).
Source: CSIS Economic Security and Technology Department.[39]

China's centralized system is not purely top-down: Its dynamism derives in part from fierce local competition that produces genuine innovations, not just subsidized scale. Using state-market hybrid institutions like government-guided funds, Beijing sets strategic priorities, while local governments, each with its own local champion firms, engage in cutthroat competition, creating lean, innovative national champions (among a sea of failures). This creates entry barriers beyond subsidies, such as battery chemistry innovations, solar efficiency breakthroughs, and cutting-edge EVs. The model works especially well for technologies requiring patient capital through thin-margin periods. However, distorted incentives such as "more is better" subsidies for publications and patents make fundamental breakthroughs harder and limit global talent attraction.

China's centralized system is not purely top-down: Its dynamism derives in part from fierce local competition that produces genuine innovations, not just subsidized scale.

Over the past two decades, China has achieved parity with the United States on technology enablers such as public-private research and education. Figure 4.3 also uses a standardized index that locates the United States and China relative to the rest of the world. Both countries generally rank highly and are largely at par across metrics for two reasons. First, China has demonstrated a consistent, long-term strategy for investing in these areas over two decades. Second, the United States has done the opposite: It has reduced public funding for R&D for decades, allowed educational standards to fall, and deprioritized reform of patent laws. Recent policy shifts, such as increased government intervention, a return to tariffs, and immigration restrictions, including on high-skill talent, further suggest a reversal of core advantages.

Figure 4.3: Technology-Specific Enablers



Note: Rescaled z-scores of select indicators (global average=50; standard deviation=20). All indicators refer to 2023 except for years of schooling (2020), R&D expenditure (2021), and public-private research (2024). Original units: R&D expenditure (% of GDP); years of schooling (learning-adjusted years of schooling); tertiary education (gross enrollment ratio - both sexes); public-private research (% of public research-industry co-publications); patent pendency (average days filing-to-grant).
Source: CSIS Economic Security and Technology Department.[40]

The rate of diffusion—the speed at which technologies scale and deploy—is now a decisive test of U.S. and Chinese approaches to economic management. The United States' institutional independence and hybrid R&D model excels at frontier innovation requiring patient capital and complex partnerships. However, corporate consolidation has weakened relationships between suppliers and original equipment manufacturers (OEMs), limiting the United States' ability to scale technologies from lab to market. China's centralized coordination excels at rapid scaling where thin margins deter private investment—a persistent challenge for U.S. capital markets, as noted above. This divergence manifests in speed of deployment: U.S. mines take roughly 29 years to progress from discovery to operation, data center queues stretch 3 to 5 years, and factories face state-by-state fragmentation.[41] China compresses timelines, setting up gigafactories from ground-breaking to production in under two years, thanks to preferential land allocation, fast permitting, and directed capital.[42] Speed, however, comes at costs that are real but often hidden, ranging from environmental harm to white-elephant projects. For technologies where time to scale determines markets, coordinated governance poses a real challenge for the United States' fragmented federalism.

These fundamental differences explain patterns across the four technology types. U.S. advantages in rule of law, capital markets, and regulatory quality enable Stack and Precision technologies that require patient capital, complex partnerships, and institutional trust. China's centralized coordination and patient state capital enable Production and Base technologies that require sustained investment through thin-margin periods and rapid scaling. Neither set of fundamentals dominates—each offers advantages for different technology types.

Technology-Specific Drivers

While economy-wide fundamentals set the stage, leadership in different technologies also depends on industrial and technology enablers, ecosystem governance, and enterprise capabilities. This section examines four technology domains through illustrative examples: AI for Stack technologies, jet engines for Precision technologies, high-end machine tools for Production technologies, and rare earths for Base technologies. These examples demonstrate broader patterns applicable to other technologies in each category.

STACK TECHNOLOGIES: COMPOUNDING ADVANTAGE

Stack technologies, such as AI, advanced chips, 5G and 6G telecommunications, and quantum computing, are composed of multiple layers stacked on top of each other, connected through defined interfaces. Advantages compound across these layers—but so do vulnerabilities. Stack technologies are distinctive because each module and layer can innovate separately and simultaneously without worrying much about how their innovations impact other parts of the ecosystem.[43] As such, lower layers enable open-ended, unpredictable innovations at higher layers. Critically, Stack technologies incorporate Precision, Production, and Base technologies simultaneously. In the case of AI, access to critical minerals and prodigious amounts of energy require massive, sustained capital; high-end chip platforms require access to semiconductor manufacturing equipment and dense global networks and accumulated expertise; and software deployment requires dense inter-firm networks.

This heterogeneity explains a key paradox: China is narrowing the gap in model quality and performance compared to U.S. frontier models and may have an advantage in AI diffusion. This is in spite of China's constraints on compute power due to U.S. export controls on AI accelerators. Compared to the United States, China had fewer "notable" models in 2024 (40 versus 15), but over time, benchmarks of its top models are similar to those of the United States across multiple metrics (see Table 4.1).[44] China could catch up because competition is multidimensional: Countries leverage selective strengths to compensate for weaknesses.

The United States leads across critical AI stack layers—in compute as well as in AI talent needed for frontier model development. These advantages derive from companies such as NVIDIA and AMD that control 90 percent or more of AI accelerator markets, along with leading universities such as Stanford, MIT, Berkeley, and others that train engineers who move fluidly between academia and industry.[45] Companies such as Microsoft, Meta, OpenAI, Anthropic, and Google are investing hundreds of billions in infrastructure and foundation models and compete on frontier capabilities through salary compensation and compute access. As a result, the United States stands alone with strengths across most of the stack. However, energy constraints, immigration restrictions, and fragmented coordination create friction. Survey results of workforce adoption of AI differ widely.[46] Little is known about the intensity, quality, and productivity effects of this usage, which are necessary to justify the massive investments and can determine the true winners of the AI race.

Table 4.1 Epoch AI Capabilities Index

	2023	2024	2025
Composite ECI Score (Avg.)			
United States	101	124	141
China	99	123	139
No. of Indexed Models			
United States	20	42	50
China	6	10	9

Note: ECI is a composite index drawing from 39 different AI model benchmarks, some of which have become saturated over time.
Source: "Data on AI Benchmarking," Epoch AI, https://epoch.ai/benchmarks.

China compensates for frontier model constraints through advantages in other stack layers and a focus on deployment. China faces severe constraints in compute under export controls, which limit its data center build-out and ability to access the most powerful AI chips. But it compensates through other layers of the stack–ingenious algorithmic efficiency, data quality and scale, and use of open-source models, all of which are powered by exceptional talent and training, strength in publications, and IP. Chinese firms focus on algorithmic efficiency, post-training optimization, data purity, and GPU networking to overcome GPU handicaps. DeepSeek appears to have demonstrated this: With most researchers trained in China, they improved competitive performance through architectural innovations, squeezing out more capability from inferior chips.[47] The company's R1 model, trained at a fraction of the cost of OpenAI's o1, achieved comparable performance through innovations in reinforcement learning and inference optimization, demonstrating that algorithmic breakthroughs can partially offset hardware disadvantages.

Deployment scale also provides feedback loops. Facial recognition, traffic management, and digital payments integrated with AI all generate massive quantities of data that improve algorithms, while government procurement guarantees that markets and SOE deployment reach scales Western firms cannot match. Although constrained by access to compute, China certainly has the capacity to build out data centers quickly. China invested $88 billion in electricity transmission and distribution in 2025 alone, with clean energy covering 80 percent of demand growth. Speed and scale enable rapid data center deployment without energy interconnection delays.[48]

AI's layered structure means neither country achieves decisive dominance. Both remain deeply interdependent, with other countries hosting centers of excellence in global value chains, including South Korean memory (SK Hynix), Taiwan-based fabrication (TSMC), Dutch photolithography (ASML), and open-source software frameworks. Advantages in Stack technologies can be established without excellence in all components of the stack. This explains why China maintains certain advantages in cutting-edge AI despite U.S. export controls, and why U.S. advantages remain real but not absolute in the most complex general-purpose technologies.

PRECISION TECHNOLOGIES: THE UNITED STATES' INDUSTRIAL MOATS

Precision technologies like jet engines, semiconductor manufacturing equipment, advanced medical imaging, industrial gas turbines, and satellite systems require decades of accumulated tacit knowledge, deep industry cooperation, sustained public-private partnerships, and certification regimes with trust premiums. These advantages create high barriers to entry, essentially creating industrial moats. Success reflects decades-long ecosystem relationships which accelerate technological capabilities, explaining why advantages persist even as competitors develop technical competence.

> *Success [in Precision technology] reflects decades-long ecosystem relationships which accelerate technological capabilities, explaining why advantages persist even as competitors develop technical competence.*

Jet engines illustrate how the United States' leadership rests on Precision technology moats. Federal Aviation Administration (FAA) certification requires thousands of testing hours, decades of operational data, and institutional relationships built on trust—taking 10 to 15 years and $10 billion per engine family.[49] This process not only enforces safety but also creates knowledge advantages. The installed base of certified, in-flight engines is central to excellence. Suppliers, OEMs, airframers, and airlines monitor equipment, collect data, train digital twins, improve reliability, and innovate on next-generation technologies. Western firms each have tens of thousands of in-flight engines; Chinese firms have none. A pedigree of installed engines is critical because multi-decade maintenance contracts such as "Power by the Hour" tightly bind ecosystem partners: risk, reward, and proprietary information is shared, and incentives are aligned. These feedback loops ensure U.S. firms such as GE and Pratt & Whitney refine engine designs generation after generation and are able to develop next-generation engines. Airlines worldwide prefer FAA-certified engines because insurance, financing, and maintenance networks align around them. There is a trust premium cementing export dominance even when competitors develop technically capable alternatives.

Defense partnerships provide another pillar of U.S. jet engine dominance. When commercial orders decline, defense sustains frontier innovation through risk-sharing and countercyclical funding. Programs like ADVENT push technological boundaries, and military requirements drive advances in materials science and propulsion that flow to commercial applications. Risk-sharing partnerships between primes and the Pentagon distribute billion-dollar development burdens, enabling innovation that commercial markets would not fund. The supplier base across specialty alloys, turbine blades, avionics, and other capabilities concentrates expertise, collaboration, and institutional memory that rivals cannot easily replicate.

While China's aerospace sector invests heavily, it struggles to match accumulated U.S. advantages. Its indigenous CJ-1000A commercial engine and WS-series military engines make progress but lag

Western performance and reliability.[50] The gap reflects not just technology but decades of tacit knowledge: U.S. firms have designed, tested, and operated tens of thousands of engines, accumulating millions of flight hours over seven decades. China can achieve competence for domestic military goals where certification differs, but commercial export competitiveness remains elusive. China does not have a single certified domestic commercial engine in the air—even one certified by China's regulator. As such, China's flagship COMAC C919 relies on Western engines precisely because certification creates high barriers for new entrants without decades of proven operational history.

The lesson with Precision technologies is to preserve the moats. That means protecting not just technology but institutional relationships, certification regimes, and public-private partnerships enabling cumulative learning across generations.

PRODUCTION TECHNOLOGIES: ALLIED NETWORKS HOLD THE EDGE

Production technologies, including high-end machine tools and machinery more broadly, diffuse widely but involve complex manufacturing processes that rely on supplier network depth, workforce skills, and continuous incremental innovation. Leadership often resides with mid-sized firms maintaining generational expertise rather than state-directed champions or finance-driven giants. This dynamic explains European and Japanese dominance despite those countries having smaller overall economies.

High-end machine tools exemplify allied production dominance and, by extension, the centrality of allied coordination for economic security.

High-end machine tools exemplify allied production dominance and, by extension, the centrality of allied coordination for economic security. Neither the United States nor China leads. Japanese, German, Italian, and Swiss firms control advanced CNC machining, five-axis milling, and high-end equipment markets. Japan's integrated conglomerates such as DMG Mori, Mazak, and Okuma, plus suppliers of critical modules like Fanuc's CNC controllers, combine machine tool production with automation systems and robotics. These firms maintain advantages through tight supplier-buyer relationships that encourage sharing proprietary information, apprenticeship programs producing highly skilled workers, and continuous incremental innovation across generations of equipment. These advantages are difficult to replicate, making allied production central to technological security.

While China represents the world's largest machine tool consumer, it remains dependent on imports of advanced components and equipment for critical sectors such as aerospace, medical devices, and advanced automotive manufacturing. Despite sustained government investments and decades of prioritizing machine tool independence, including through the country's Made in China 2025 strategy, Chinese firms struggle in high-end segments requiring extreme precision and reliability.[51] China produces volume in lower-end categories but cannot match European or Japanese performance. The gap reflects not just technology but manufacturing culture: German Mittelstand firms and Japanese conglomerates built advantages through generational expertise, apprenticeship systems, and customer co-development that state-directed approaches struggle to replicate.

The United States tells a different story—one of lost leadership as domestic firms have underinvested and supplier networks have atrophied. U.S. machine tool production retained a global lead in the early 1980s but declined with that decade's recession as production factories sought rock-bottom-cheap machinery. Longstanding OEM-supplier relationships were broken up and long-held tacit knowledge eroded as capital markets pressured cyclical, low-margin industries and federal policies reduced tax incentives for industrial investment. Recent federal efforts through the Manufacturing USA institutes and the Manufacturing Extension Partnership aim to rebuild capabilities but face structural challenges, including inadequate budgets, fragmented supplier bases, the loss of tacit knowledge, and limited apprenticeship systems compared to Germany and Japan.[52]

This comparison reveals that Production technologies reward sustained manufacturing focus, the fostering of patient capital, supplier network depth, and workforce development over decades—capabilities neither the United States' finance-driven fragmentation nor China's state-directed scale have successfully replicated. Production technologies underscore how and why allies matter: Europe and Japan provide critical production capabilities neither the United States nor China can rapidly rebuild or accumulate, making allied coordination key to each nation's technological security and ability to scale future technologies.

BASE TECHNOLOGIES: CHINA'S PATIENT CAPITAL ADVANTAGE

Base technologies such as the processing of steel and aluminum, rare earths, critical minerals, and basic chemicals underpin industrial bases and advanced technologies. Lower production complexity and ease of concentration of these technologies create opportunities for strategic leverage when production and suppliers are concentrated. China's structural advantages stem from tolerance for sustained negative economic returns: firms operating with returns on invested capital (ROIC) below their cost of capital (WACC), destroying economic value while driving competitors out. This dynamic reflects the non-commercial interests of state banks and state-owned enterprises (SOEs), plus intense competition between local governments nurturing local champions. The effect is systematic market failure where patient capital, price predation, and market scale overwhelm profitability requirements that discipline Western firms and their investors.

Lower production complexity and ease of concentration of [Base] technologies create opportunities for strategic leverage when production and suppliers are concentrated.

BOX 4.1

Emerging Technology Partners for the United States: Saudi Arabia and the United Arab Emirates

Saudi Arabia and the United Arab Emirates (UAE) are rapidly evolving into critical technology partners for the United States, extending long-standing relationships historically focused on energy and defense. This transformation is driven by a strategic shift in the Gulf states to secure new economic and geopolitical footholds beyond traditional hydrocarbon industries within an increasingly multipolar landscape shaped by the global technology race. This shift is exemplified the UAE's Centennial 2071 and Saudi Arabia's Vision 2030.[53]

The core of the emerging U.S.-Gulf partnership centers on co-developing frontier technology infrastructure. The UAE's state-linked AI firm G42 is a pioneer, aiming to construct one of the world's largest compute hubs in Abu Dhabi.[54] Central to this is the planned U.S.-UAE AI Campus, which will integrate key U.S. AI stack firms, including NVIDIA, OpenAI, Oracle, and Microsoft.[55] Similarly, in Saudi Arabia, the Public Investment Fund's AI vehicle, Humain, is advancing joint bilateral AI infrastructure development through procurement of advanced NVIDIA Blackwell chips and partnerships with AMD, Cisco, and xAI.[56] A major milestone was reached in November 2025 with the U.S. Commerce Department's approval for the sale of tens of thousands of advanced AI chips to Gulf firms, with the deployment governed under the department's Regulated Technology Environment (RTE) framework.[57] For Washington, these collaborations offer concrete opportunities to scale AI infrastructure and AI-enabled service exports beyond the U.S. market.

Beyond AI, the partnership is deepening across other sectors critical to economic security. The May 2025 U.S.-UAE agreement secured $200 billion in new commercial deals, including a UAE investment into developing an aluminum smelter project in the United States, along with an RTX/Tawazun Council gallium project to stabilize U.S. critical mineral supply chains.[58] As an outcome of the November U.S.-Saudi Arabia summit, the two countries expanded their partnerships to include civil nuclear energy, critical minerals cooperation, and an AI memorandum of understanding that would provide Saudi Arabia access to advanced U.S. AI technologies.[59]

Despite ongoing progress, challenges remain. The United States faces risks such as technology diversion to strategic competitors, IP theft, and ethical concerns tied to state-linked surveillance, amplified by the absence of transparent, independent AI regulatory frameworks in both countries.[60] To fully realize the potential of these partnerships sustainably, Washington needs to condition Gulf States' access to critical technologies and investment in the U.S. technology ecosystem on broader strategic alignment, including clear commitments to adopt AI safety, governance, and ethical standards consistent with U.S. frameworks.

Rare earths exemplify China's approach to Base technology dominance achieved through decades of patient investment, industry consolidation, vertical integration, and ecosystem strengths beyond industrial policy. As a result, China mines 60 percent of global rare earth supply and processes over 90 percent.[61] While U.S. producers were facing environmental challenges and thin margins in the 1990s and 2000s, China identified the strategic importance of REEs early and quickly expanded capacity, accepted environmental costs, and applied a panoply of price controls and production and export quotas. Chinese firms also innovated over time, filing 26,000 REE patents between 1950 and 2018, compared to around 10,000 by U.S. firms. China has perfected refining processes and is now globally dominant.[62]

China also achieved industrial consolidation and vertical integration through acquisitions and forced licensing. Its acquisition of GM's Magnequench and forced licensing of Hitachi's neodymium-iron-boron magnets enabled Chinese control from mining through magnet production.[63] In prior decades, local governments competed to build processing capacity through unprofitable periods while SOE procurement guaranteed demand. Beijing shut down hundreds of local mines and enforced industry consolidation into two SOE conglomerates. China's control over the industry enables its coercive strategies used against the United States and allies—most recently through its October 2025 export restrictions covering REEs and permanent magnets, which were unprecedented in their extraterritorial reach.[64]

The United States' once-formidable advantages in REE processing eroded through Chinese price predation leading to market exits and regulatory constraints. Recent federal interventions such as the Department of Defense's investment in MP Materials under the Defense Production Act, Department of Energy loans, guaranteed price floors, and magnet procurement all aim to rebuild capacity and protect the industry from Chinese predation. However, structural constraints persist, such as long timelines for new mines, thin margins deterring private capital, and workforce gaps in REE expertise.[65] Actions by allies such as Australia tripling oxide output and Japan expanding refining provide some diversification, but separation and magnet production remain concentrated in China.

Strategic Implications: The Dexterity Imperative

The illustrative cases show that dexterity can be built, and where necessary, rebuilt. The United States excels in Stack technologies (e.g., AI and advanced chips) and Precision technologies (e.g., jet engines) where deep capital markets, institutional trust, and certification regimes create compounding advantages. China dominates Base technologies (e.g., rare earths, steel, and solar) and select Production technologies, where patient state capital and coordinated permitting sustain thin margins through learning curves. Neither country has absolute advantages across all technology types, nor can either easily replicate the other's institutional capabilities.

Three strategic insights follow. First, weaknesses cascade, while strengths compound. U.S. gaps in Production and Base technologies threaten Stack technology advantages; conversely, U.S. excellence in Stack and Precision technologies creates feedback loops that reinforce each other. Second, America has demonstrated, and can rebuild, dexterity across technology types. Jet engines provide evidence that Precision technology moats endure, and AI leadership shows that Stack technology advantages remain formidable. The challenge is to rebuild capabilities in Production and Base technologies where the United States once led. Third, allies and trading partners, including new technology partners (see Box 4.1), hold the balance of power—a historic American strength. Machine tools from Germany and Japan, memory chips from South Korea, and lithography equipment from the Netherlands are examples of critical inputs to one or more acceleration technologies—underscoring that allied coordination provides advantages China cannot replicate.

America cannot afford to specialize narrowly. It must rebuild the ecosystem capabilities necessary to compete across all four technology types, using traditional and new allies as force multipliers. Chapter 5 offers a playbook for how to do this: preserving Precision technology moats, rebuilding Production technology through allies, securing Base technology supply chains, and extending Stack technology leadership through the tailored strategies that technological dexterity demands.

BOX 4.2

Towards a Quantitative Approach to Benchmarking Ecosystems

Future research by the CSIS EST Department will convert the qualitative U.S.-China scorecards in this report into a structured, data-driven comparative assessment. The quantification project will utilize the basic scorecard structure in this report (four industries and three industry-specific building blocks) and collect bespoke data on each industry. Industry specificity of the data is important because firms today are highly specialized and even relatively narrow industry data (e.g., NAICS) tends to contain substantial heterogeneity. This is insufficient in a world of very complex value chains and narrow chokepoints. For instance, REE mining-to-processing is very different from the iron ore value chain, but these would normally be mixed together in most data.

However, compared to this report, the future project will be more systematic in breaking each building block into its critical sub-categories (e.g., technology enablers would include factors such as talent, research, infrastructure, and finance) and also be systematic in collecting data on each. Quantification will provide several benefits. It creates a stable comparative framework that will allow EST to track changes in relative competitiveness across industries over time. Furthermore, a quantitative index that aggregates across multiple indicators allows researchers to drill below the surface to compare the United States and China within particular sub-categories (e.g., AI talent, AI compute, and AI research) while still aggregating up to overall assessments.

5

How America Can Play the Technology Long Game

Chapters 1-4 show that leadership varies widely by technology but always flows from ecosystem strengths—not from a single breakthrough. The United States remains strongest in Stack and Precision technologies; China has consolidated advantages in Base technology inputs and is gaining in parts of Precision and Production technologies. Neither the U.S. nor the Chinese system is purely top-down or purely bottom-up; both blend public purpose and markets, though in different ways. Leadership will belong to the country with dexterity across these technologies, as well as the ability to translate discovery into deployment and diffusion at pace and at scale.

This chapter moves from diagnosis to creating a living playbook to win the technology long game. The United States must (1) "play all the keys" by developing dexterity across technology types, (2) make speed-to-scale the organizing principle for enabling infrastructure and technology diffusion, and (3) defend its networks of innovators at home and abroad against mercantile and malign threats. Success requires new policy tools, the personnel to wield them, and strategic capability to stay the course. It also requires running pilots and experiments, allowing room to fail and learn, and finding pathways to scale what succeeds.

Playing All the Keys

This section lays out how to rebuild the fundamentals—R&D, workforce, and patient capital—so the United States can compete across all four technology types.

Technology dexterity starts with time-tested economy-wide fundamentals: open and predictable institutions, sound macro-fiscal management, and a culture that rewards risk-taking and innovation. The United States cannot afford to backslide on these distinctive advantages. Sustainable public finances are essential to preserve dollar dominance, signal the long-term stability that attracts patient capital and ambitious talent, and reprioritize public spending toward investment in productivity-enhancing enablers.

Investments in enablers with spillovers across technology domains are essential. . . . these types of investments do not pick technology winners—they expand the space for possible winners.

Investments in enablers with spillovers across technology domains are essential. These include productive R&D that translates to commercial outcomes, workforce development with both depth and breadth, energy infrastructure to meet industrial and technology demands, and cultivation of capital willing to back long-horizon bets. It is important to underscore that these types of investments do not pick technology winners–they expand the space for possible winners.

PRODUCTIVE RESEARCH AND DEVELOPMENT

The United States must reverse declining research productivity through a multipronged effort involving the national labs, grand scientific challenges, and private sector tax incentives. The Trump administration's recently launched Genesis Mission demonstrates this approach: deploying AI to accelerate scientific discovery through outcomes-based "grand challenges" with staged prizes at bench, pilot, and commercial scales. These challenges could include targets like direct lithium extraction, modular REE separation, ultra-low-energy compute, and bio-based substitutions for hazardous chemistries. As Genesis generates early wins, Congress should expand multiyear appropriations for use-inspired research with clear paths from grant to testbed to procurement. Advance purchasing commitments from federal agencies and private buyers pull innovations forward. Time-bound tax credits and performance standards incentivize private R&D to accelerate outcomes.

That alone will not be enough. In parallel, the administration and Congress must act to stabilize and increase funding for basic research in lock-step with stronger research security safeguards. The basics remain essential: Congress should sustain multiyear appropriations for basic research, such as through the "Science" part of the bipartisan CHIPS and Science Act. Universities and national laboratories that receive public support should demonstrate high standards for research-security with respect to disclosure, data, and IP while preserving sensible collaboration.

WORKFORCE DEPTH AND BREADTH

Workforce development receives significant attention and funding across federal, state, and local governments, as well as from private sector firms. Yet the skills gaps have persisted–particularly in advanced manufacturing, trade skills, and specialized construction for AI infrastructure. The problem is fragmentation and subscale efforts. Numerous vocational programs scattered across community colleges, universities, and firms create uncertainty about which credentials are valuable and which pedagogical methods work best. Differing certifications across state borders hamper geographic mobility, while employer-specific training creates workers with limited portability of skills. The productivity of training matters as much as the productivity of the trained—yet neither are tracked, benchmarked, and shared widely. The barrier to entry is low for new workforce training programs, and the barrier to scaling is high. The result is a proliferation of subscale training programs, making it hard for the best ones to scale.

Rather than creating yet another public program, the solution is national goal-setting and public-private coordination. For instance, to meet the significant labor demands for AI infrastructure and advanced manufacturing—including specialized electricians, construction workers, and HVAC operators—a National AI Workforce Consortium should be established as a public-private partnership that (1) sets common standards and credential frameworks, (2) assesses and compares the productivity of training programs, (3) helps industry associations and unions grow paid, standardized apprenticeships tied to live projects and benchmarked nationally, and (4) helps industry stand up a national instructor corps to surge capacity.[66] Such a consortium could also help state licensing boards adopt interstate reciprocity to ensure portability of credentials. Community colleges and technical schools should have access to already appropriated federal infrastructure funds to upgrade labs for power, thermal, controls, and commissioning.

PATIENT CAPITAL MECHANISMS

Replicating China's state-directed patient capital model and tolerance for profit destruction is not the answer. The United States, however, should develop targeted mechanisms in areas where markets systematically underinvest. The Defense Production Act authorities should be fully leveraged to de-risk investments in rare earth separation, refining, magnet, and battery materials plants through fast-track permits, time-limited credits, and targeted production support.

The United States and its partners should also establish a Technology Dexterity Fund that pools resources committed under recent trade and investment agreements with South Korea, Japan, and the United Kingdom, as well as recent investment framework agreements with the UAE and Saudi Arabia. Committed public and private investments from these partners could be co-mingled with investments from American limited partners to seek returns in economic security domains—early-stage investing in emerging technologies; supply chain resilience, including in Base technologies; and in technologies that no single country can shoulder alone, such as advanced semiconductor and electronics packaging, sintered magnets, precision subassemblies, machine-tool classes, and advanced materials. Capital would flow in staged tranches tied to performance gates—such as commissioning, throughput, yield, and cost declines—with reciprocal market access and common standards built into every award.

TAILORING STRATEGIES TO TECHNOLOGY TYPES

Playing all the keys requires more than investments in R&D, workforce, and patient capital: It requires strategies tailored to each technology type—a core insight from Chapters 2 through 4.

Different technology types demand different policy instruments and institutional capabilities. Any viable technology long game requires that the United States (1) revive its industrial base in Base technologies where China wields leverage, such as in critical minerals, batteries, solar, and wind energy; (2) lean on allied networks in Production technologies where historical partners are strongest; (3) fortify industrial moats to make Precision technology leadership durable; and (4) compound advantages across Stack technologies, such as in both the compute and applications sides of the AI stack (see Box 5.1).

BOX 5.1

Tailoring Strategies to Technology Types

- **Revitalize and innovate in Base technologies by securing U.S. access to mining, developing processing capacity at home and with allies, and innovating away from chokepoints.** The United States should expand stakes in global extraction by using the U.S. Export-Import Bank's China and Transformational Exports Program as well as the U.S. International Development Finance Corporation, export credit, and offtake-backed equity to secure high-standard mines in trusted jurisdictions. The United States should indigenize processing by recruiting partner foreign investment to build separation, refining, magnet, and battery materials plants in the United States, de-risked with fast-track permits, time-limited credits, community-benefit agreements, and targeted support under Title III of the Defense Production Act. In parallel, it should lean on allied processing through co-funded facilities and pooled procurement with Australia, Japan, Canada, and Europe, with shared specifications and assured access to maintenance, spares, and quality data. Strategic stockpiles should be sized to realistic shocks and managed with transparent rotation rules and price bands. Finally, the United States should change the bill of materials through grand scientific challenges and first-buyer commitments for REE-free traction motors, sodium-ion and low-lithium batteries, copper-lean conductors, high-recycled steels and aluminums, and "designed-for-recycling" components, helping to reduce dependence on vulnerable inputs over time.
- **Defend networks with advantages on Production technologies.** High-end machine tools, precision subassemblies, and specialized equipment are dominated by firms in Europe and Japan that have sustained generational expertise through supplier depth, apprenticeship systems, and continuous incremental innovation. The United States should be selective about what to rebuild domestically and be honest about trade-offs. For defense-critical applications with few substitutes and long replacement lead times, selective domestic capacity makes sense; for many other segments, the resilient path is cost-efficient access through allied partnerships. A jointly capitalized pipeline of pilot lines in allied jurisdictions—tied to reciprocal market access, common standards, and assured maintenance and spares for U.S.-based strategic users—will deliver resilience faster than broad reshoring mandates. U.S. firms should focus

domestic build on genuine bottlenecks and pursue licensed production or joint ventures for niche gaps that benefit from proximity to users.

- **Fortify the moats around Precision technologies—but make them compete at home.** The United States leads in jet engines, some semiconductor tools, oil and gas extraction equipment, industrial turbines and advanced medical imaging. Competitiveness in each area rests on some combination of certification, defense partnerships, deep supplier and customer collaboration, and sharing of proprietary assets based on trust. These relationships need to be nurtured and protected. The Department of Commerce needs to continue to lead and cooperate with partners, ideally through a new and updated COCOM regime that strategically targets China, controls critical commercial products, and harmonizes licensing. The United States should use strategic tariffs and targeted, reversible import bans to counter dumping, coercive licensing, transshipment, data risks, and component integrity issues. Agencies should enforce strict origin checks and procurement exclusion lists to block backdoor entry. Protecting advantage vis-à-vis China should not be a reason to protect domestic incumbents. The Department of Commerce, Department of Defense, Federal Trade Commission, and related agencies should implement pro-competitive procurement, open standards, and active antitrust to encourage entry and reward performance. Agencies and prime contractors should maintain continuity plans—including bridge contracts, shared testbeds, and qualified-supplier programs—to preserve tacit capabilities if firms stumble.
- **Compound advantages across Stack technologies by tightening the basics and speeding diffusion.** Stack technology is layered, involving hardware, infrastructure, algorithms, data, and applications. Advantage compounds across those layers, as do vulnerabilities. This report focuses on AI. On the compute side, the United States should maintain strict export rules on cutting-edge chips and tools so that rivals do not use them for military applications, along with nuanced policy on "renting" compute through American hyperscalers. In parallel, it should streamline onerous regulatory bottlenecks to building data centers and chip fabs. That will also require coordinated training of skilled labor such as electricians and technicians. On the application side, the emphasis should be on diffusion. A number of measures should be considered, including setting a national baseline for data privacy and AI safety rather than a regime fragmented by states.

Achieving Speed and Scale

This section focuses on closing the deployment gap by pursuing faster permitting, better testing infrastructure, and real diffusion into firms.

The United States invents but struggles to deploy at the speed and scale the competition demands. The deployment gap results most obviously from three bottlenecks. Slow permitting stretches core infrastructure timelines to decades, delaying the energy and interconnection that advanced manufacturing and AI data centers require. Without shared testing and qualification infrastructure, startups cannot validate technologies at scale, forcing them into captive supplier relationships or abandoning commercialization entirely. And even when technologies prove commercially viable, diffusion remains glacially slow—with large gaps between a few firms that change core workflows, worker tasks, and business processes, and the vast majority that do not. These bottlenecks reinforce each other: Infrastructure constraints limit the availability of test facilities, testing gaps slow the qualification cycles that enable diffusion, and poor diffusion rates undermine the business case for new infrastructure investment. For technologies where deployment pace determines market capture, breaking this cycle is existential.

SPEED-TO-POWER IN ENERGY AND OTHER CRITICAL INFRASTRUCTURE

To deliver on enablers such as energy and interconnection, regulatory streamlining and capability building are essential. High-profile industrial and energy megaprojects in recent years have seen construction schedule overruns, unforeseen permitting issues, and increases in project costs. Stakeholders in the emerging technology and industrial ecosystem are confronted not just with technical risk and capital risk—they must also navigate project delivery risk. But there are ways to reduce uncertainty without compromising on stringency. The Federal Energy Regulatory Commission and state commissions could run concurrent reviews with predictable interconnection clocks. The Department of Energy could coordinate pre-permitted transmission corridors and fast-track constrained regions. Federal and state governments could impose shot-clocks on megaproject permitting and shift toward envelope-based permits. Congress and states could buy down costs for nationally strategic projects while requiring minimum standards for construction design and contingency planning. Industry consortia should aggregate data on construction productivity and track the adoption of lean construction practices. Voluntary performance thresholds could assess project readiness. Expanded training programs for skilled trades need consistent metrics to assess and scale effective workforce investments.

ACCELERATE ENGINEERING AND TESTING

Chapter 3 noted that federally funded R&D has declined as a share of GDP even as the engineering and manufacturing base has hollowed out, creating a “missing middle” between upstream research and downstream commercialization. The United States has lost between one-third and nearly half of its firms in critical “industrial commons” sectors—such as machine tooling, electronics packaging, metal foundries, tool and die makers, and forging—since the late 1990s.[67] America now lacks shared testing infrastructure to move technologies from lab to market. In the absence of accessible testing and engineering facilities for qualification, innovative startups can exhaust investor patience, fail at technical qualification, or become captive suppliers to the OEMs that open up their own facilities but maintain control of test datasets. Closing this gap requires investment in virtual prototyping—including cloud infrastructure, datasets, software tools, digital twins, and IP libraries—and an expansion of shared physical assets and test datasets. One place to start is refocusing Manufacturing USA institutes on end-to-end pilot lines and the full testing and qualification pathway. Institutes should emphasize end-use customers, enable tool and supplier qualification, and own the shared qualification datasets on behalf of industry. Today, only about 5 percent of more than 450 Manufacturing USA projects have reached pilot-scale validation, a rate that must improve dramatically.[68]

DRIVING DIFFUSION

Testing infrastructure enables commercialization, but commercialization does not guarantee adoption. U.S. firms dominate AI stack layers—it holds more than 90 percent of the GPU share and had 40 notable models versus China's 15 in 2024—but only 7 percent of large U.S. firms have fully deployed and integrated AI across their organizations.[69] This addresses the myth (#4 from Chapter 1) that America cannot win by focusing only on frontier technologies like AI. The problem is not invention but diffusion. The barriers are organizational, including a lack of workflow redesign, poor adoption practices, skills gaps, and unclear value measurement.

Sector-specific enablers would accelerate adoption where barriers are highest. Small healthcare firms struggle with transforming care delivery workflows. Small manufacturing firms face supply chain integration challenges and expertise gaps despite pockets of success in predictive maintenance. Smaller firms can benefit from customer requirements that accelerate adoption: AI-enabled project management or digital twins for infrastructure projects can drive AI adoption among smaller design and construction firms. Smaller firms face hurdles from state-by-state compliance fragmentation. A national baseline for data privacy and AI safety would reduce this complexity and accelerate AI adoption across supply chain boundaries.

Defending the Network

This section shows how to protect U.S. and allied ecosystems with surgical controls, conduct-based trade remedies, and modern investment and IP screening.

Defense requires calibration against malign actions, modern mercantilism, and supply chain exploitation that threatens American innovation. But overly broad controls isolate ecosystems, deter top talent, and fragment the allied collaboration that creates advantages. Chapter 1's Myth #5 warned against dismissing national security risks—dual-use threats, cyber vulnerabilities, and supply chain dependencies are grave and accelerating. U.S. cloud providers essentially trained the Chinese AI models that are now powering the surveillance capabilities of the People's Liberation Army; the United States' defense industrial base grew dependent on Chinese "legacy" chips; and semiconductor equipment sales have accelerated Beijing's chip manufacturing capabilities. The goal is balanced protection across three mechanisms: (1) narrower and faster controls on real leakage paths, (2) the screening of predatory investment before capital creates leverage, and (3) the creation of positive frameworks for allied cooperation that reduce dependence on adversarial sources while preserving the openness that innovation requires.

EXPORT CONTROLS AND IMPORT RESTRICTIONS

Export controls have been increasingly used to restrict China's access to sensitive U.S. technologies, particularly in Stack and Precision technologies, for its military modernization. The controls also serve to preserve technological advantages over China more generally. But extensive use of such tools comes at a cost: It can shut U.S. firms out of the fast-growing Chinese market, cede revenue growth and market share to competitors, including domestic firms in China, and limit U.S. firms' ability to recycle income back into domestic R&D.[70] With increased technological complexity, more combinatorial pathways to pursue the technology frontier, and firms' tendency to operate just below the export-control threshold, the effectiveness of controls in retaining U.S. leadership remains hotly debated. Meanwhile, Chinese policy shows little hesitation in deploying its own export controls (such as in rare earths) and import restrictions to support domestic manufacturers to benefit homegrown Chinese firms, as it has done against U.S. memory producers and, most recently, NVIDIA AI chips.

Export controls must be more multilateral and surgical. Their enforcement must be supported by fast-action capabilities.

First, export controls must become more surgical and faster to implement. Broad controls that shut U.S. firms out of Chinese markets hand revenue and learning curves to competitors–outcomes antithetical to U.S. interests. Controls should prioritize real leakage paths and guide Chinese firms toward controllable U.S. products. For instance, export controls on AI chips should remain high; however, although lawmakers have raised concerns about the "cloud loophole," Chinese firms should be actively encouraged to train their models on U.S. cloud computing, where activity can be monitored with new know-your-customer (KYC) authorities, and services can be immediately cut off for military uses. At a minimum, keystone allies should be encouraged through minilateral arrangements to upgrade their controls and enforcement to remain aligned with U.S. strategic goals, as well as to create an even playing field, enhance enforcement, and allow rapid updating as evasion tactics shift. At best, a new multilateral regime similar to the former COCOM would fix the weaknesses of the Wassenaar Arrangement, such as a lack of China-targeted strategic goals, slow focus on commercial innovations, and the lack of harmonized licensing and enforcement. Finally, how controls are applied matters as much as which controls are applied. Export controls have proven to be a fast-moving cat and mouse game: Slow and cumbersome interagency processes are no match for nimble firms or adversarial actors bent on finding workarounds. The process needs more funding to allow for tighter policy cohesion, faster technical analyses, better economic intelligence, and keener monitoring and responses to perceived end-runs.

Second, import restrictions should target conduct, not sectors. Without well-designed import remedies, U.S. incentives to attract private capital for domestic capacity building remain vulnerable to the profit destruction and scorched-earth tactics of non-market Chinese competitors. Remedies at the border should be imposed on a conduct basis–targeting behaviors such as below-cost dumping, coercive licensing, and investment practices that erase rivals–not as blanket sectoral bans. Sunsets and periodic tests of necessity should be standard practice. The message to firms should be clear: You are welcome to compete on innovation and efficiency, but compete by destroying the markets that fund innovation and you will face targeted, time-bound consequences.

IP PROTECTION AND INVESTMENT SCREENING

There is a need to modernize IP protection in this era of technology competition. The current patent system assumes respect for IP, but firms today face a far different reality rife with systematic and rampant IP theft, forced technology transfer, and adversarial capital targeting innovative startups. Congress should consider expanding CFIUS authorities to screen investments before capital creates leverage, while strengthening export control authorities to prevent transfers of foundational IP through licensing, joint ventures, or personnel exchanges. Equally important is heightened scrutiny of university research partnerships with adversarial nations. In addition, civil and criminal penalties for IP theft should be considered to reflect the strategic value of stolen technology, not just commercial damages. These measures can help protect the advantages U.S. researchers and firms have helped create over decades.

TECH-FRIENDLY TRADE AND INVESTMENT COMPACTS

Current trade policy strains allied relationships essential to technology leadership. Chaotic tariff moves have isolated the United States from partners, such as German machine tool makers, Japanese advanced materials and precision manufacturers, South Korean advanced battery producers, and Dutch semiconductor equipment makers, who are deeply integrated with U.S. firms and are force multipliers of U.S. innovation. Allies face competing pressures from Chinese market access, capital offers, and technology transfer demands. Without positive frameworks for cooperation, allies will hedge between U.S. and Chinese ecosystems, weakening the networks that underpin U.S. innovation.

Tech-friendly trade compacts could provide tariff reductions in exchange for technology cooperation and supply chain resilience. Tariff relief could be earned through verifiable milestones: joint standards work, capital committed to build critical nodes in the United States, reductions in China-sourced inputs, and establishment of countercyclical stockpiles, crisis response mechanisms, and assured-access frameworks. Duties would ratchet down as milestones are met and snap back if commitments lapse. Rules of origin would count cumulatively across compact members. The Blue Dot Network, a certification framework for quality, sustainable infrastructure projects originally launched by the United States, Japan, and Australia and now extending across OECD countries, can serve as a model for a Resilient Supply Chain Network. Elements of such a pact exist: recent trade deals with Japan, South Korea, the United Kingdom, and others provide forums where criteria can be negotiated, progress monitored, and disputes resolved.

BRINGING IT ALL TOGETHER

The three strategic pillars–play all the keys, speed to scale, and defend the network–are mutually reinforcing. Without speed to scale, playing all the keys becomes aspirational rather than operational, leading to research that never reaches pilot scale, workforce programs that never achieve critical mass, and allied partnerships that never move beyond MOUs. Without defending the network, scaling advantages can become vulnerabilities, such as when domestic capacity is undercut by predatory pricing, allied partnerships are disrupted by Chinese capital offers, or innovations are leaked through forced technology transfer. Without playing all the keys, speed and defense address symptoms rather than causes: Faster permitting cannot compensate for losing Production technology capabilities, and tighter export controls cannot substitute for building Base technology resilience.

The private sector cannot deliver on its dynamic potential if government efforts remain fragmented and slow.

Executing this strategy requires reforming and building new capabilities within U.S. government institutions. The private sector cannot deliver on its dynamic potential if government efforts remain fragmented and slow. Without a central strategic capability and a new generation of "economic warriors," none of the three prongs presented here can be coordinated or sequenced effectively.[71] The United States needs a combined economic security and technology capability at the center of government to drive this technology playbook, including the ability to coordinate across the Departments of Commerce, Energy, Defense, and the Treasury, as well as with the U.S. intelligence community. This capability should have authority to convene principals, direct interagency processes, allocate budgets across competing priorities, and report directly to the president on technology competition metrics. It should combine elements of the National Economic Council's coordination function, the National Security Council's strategic planning, and the Office of Science and Technology Policy's technical expertise—but with clear accountability for technology competition outcomes.

Everyone Has a Part to Play

The United States can win the technology competition by maintaining frontier innovation advantages while closing deployment gaps—not by replicating China's state-directed model. Success should be measured by the United States's ability to maintain its depth of integration with allied networks that China cannot penetrate, its standards dominance that shapes global markets, and its talent magnetism, which China has not yet matched despite massive spending. The United States possesses distinctive strengths, including the ability to course correct, to invent and build, to attract global talent through openness, and to mobilize capital through market signals.

Playing the long game requires clarity of goals, consistency, coordination, and staying power—qualities that transcend short electoral cycles and America's boisterous politics. Federal agencies must coordinate across departmental boundaries. States must align workforce certifications and regulatory frameworks. Congress must appropriate for multiyear horizons, use its oversight authority to prioritize the coordination of individually legislated federal programs, and assess their performance against the original policy objectives, not against metrics meant to reflect program sustainability. Allies must see predictability in commitments. Advantages that take decades to build—including certification regimes, supplier networks, and standards dominance—cannot survive priorities that reset every two years.

The myths that opened this report need not hold the United States back. America has prodigious talents, capabilities, and resources. Everyone has a part to play, including the federal government, state and local governments, the private sector, investors, universities, community colleges, and workers. As Ralph Waldo Emerson said, "Do the thing, and you shall have the power."[72] That truth holds for every American in the technology long game.

Part II

National Ecosystems in Action

6

China’s Technological Ascent

Scale Advantages, Network Barriers

In two generations, China has moved from a largely agrarian economy to a global innovation pace-setter with frequent breakthroughs in important technologies such as AI, EVs, robotics, and pharmaceuticals. That arc has fueled both anxiety about the economic and national security challenges that China poses to the West and curiosity about the sources of its success that others might adapt. China’s path—which has in many ways been purposeful—has been anything but linear (Box 6.1). Analysts who highlight China’s successes make it sound like China is an unstoppable juggernaut; those that focus on its weaknesses make it sound like a victim of the middle-income trap. The reality is that China’s innovation ecosystem displays remarkable strengths alongside persistent weaknesses. Some industries have leapt ahead to world-class performance, while others still lag far behind, even those prioritized by Beijing and flush with capital. The challenge is understanding the underlying ecosystem factors that drive this differentiation, which requires understanding both China and core elements of its competitiveness across industries.

This chapter takes this complexity seriously and analyzes China through the common lens used across this report. It draws on a brief historical backdrop and then assesses four building blocks—economy-wide fundamentals, technology-specific enablers, ecosystem governance, and enterprise capabilities—while mapping outcomes across four technology types: Stack, Precision, Production, and Base. The aim is to show where China’s institutional features are fit for purpose and where they are misaligned. In doing so, this chapter identifies patterns that matter for policy—areas where patient capital and vertical integration confer leverage (Base technologies), where talent cultivation and supplier density drive diffusion (Production technologies), where trust-based business networks and decades of tacit know-how protect incumbents (Precision technology), and where deployment and software excellence partially offset hardware constraints (Stack technology).

BOX 6.1

Historical Evolution of China's Technology Strategy

China's coherent industrial policy emerged gradually. During Deng Xiaoping's Reform Era, Beijing permitted private businesses, created special economic zones, pursued foreign investment, and sent students abroad. Initial industrial policies targeting semiconductors and automobiles appeared in the mid-1990s but lacked coordination and funding.

The decisive shift came in 2005 with "indigenous innovation" (*zìzhǔ chuàngxīn*, 自主创新), a policy framing which has stressed developing domestic technologies and increasing domestic value added across supply chains. The 2006 National Medium- and Long-term Science and Technology Development Plan (2006-2020) emphasized indigenous innovation as a strategic priority. In 2009, China announced a focus on roughly two dozen "strategic emerging industries," similar to U.S. and EU priorities.

China's state-led industrial strategy, Made in China 2025, announced in 2015, refined this approach with specific targets for market share. Though essentially import substitution, Made in China 2025 still envisioned China operating within stable global supply chains. Rising tensions during the first Trump administration and the subsequent Biden administration—with expanded U.S. export controls and investment restrictions—shifted Chinese policy toward technological self-reliance, solidified in the 14th Five-Year Plan (2021-2025). The return of Trump administration policies in 2025, including renewed tariffs and expanded technology restrictions, has further accelerated the urgency with which China has pursued technological autonomy.

Policy has been relatively coherent compared to most governments, though implementation reflects tensions among economic and security objectives, central and local bureaucratic preferences, business lobbying, and the physical realities of technologies and industries.

Key inflection points include the following:

- **1978-2005:** Reform and opening, initial technology zones, foreign investment
- **2005-2015:** Indigenous innovation era, strategic emerging industries identified
- **2015-2020:** Made in China 2025, targeted market share goals
- **2020-present:** Self-reliance emphasis following U.S. export controls and tariffs

Economy-Wide Fundamentals

Across a broad swath of measures, China's broad economy-wide institutions and macroeconomic health scored a 57, compared globally with a world average of 50 (see Chapter 4, Figure 4.1). China exhibited particular weakness in rule of law and institutional quality, while its strengths are particularly geared toward advancing its technological upgrading, including patient capital, skills improvement capabilities, rapidly expanding infrastructure, including in new energy, and growing global engagement. Yet even in these areas of strength, some challenges persist. Moreover, China's unique center-local government dynamic is a structural feature that produces both advantageous and negative outcomes.

China's innovation environment combines durable macro-stability with structural frictions. Since the mid-1990s, consistent growth targets and relatively disciplined monetary policy have supported long investment cycles, despite fiscal pressures (e.g., tax receipts near 14 percent of GDP and rising local liabilities) and uneven competition policy (e.g., SOE oligopolies in strategic sectors). This financial structure and soft budget constraints continue to drive overinvestment, with investment making up over 40 percent of GDP for the past two decades.[73]

Despite "self-reliance" rhetoric, international linkages are crucial to maintaining domestic capabilities if China wishes to pursue the leading edge.

Long-horizon "patient capital" has been a consistent feature of technology upgrading. State banks, local governments, and government guidance funds—alone targeting 13 trillion RMB ($1.9 trillion) in 2022—channel multiyear finance into priority sectors such as semiconductors (including $150-$200 billion in national and local state-led investments, such as the "Big Fund," between 2014 and 2024), green energy, batteries, and selected digital infrastructure, among others.[74] These capital sources are willing to accept periods where return on capital is lower than the cost of capital. This represents a trade-off between corporate profits and achieving goals, such as technological upgrading and market share. When value destruction has allowed China's national champions to capture global market share, it appears to be a winning strategy, even if it raises questions of market viability and overall allocative efficiency.

China's local governments direct investments and other advantages to preferred industries in order to promote local-cum-national champions; however, this often leads to returns on capital below its cost and pressure to expand into new markets, creating frictions in foreign trade. Beijing typically sets priorities and facilitates resource allocation to preferred technologies, but local governments are often key implementers of industrial policy in China. Soft budget constraints as well as the built-in incentive for localities and officials to achieve growth and meet central targets can lead to local overreaction. Local governments end up throwing capital at Beijing's priorities in some sectors, sometimes with little due diligence or consideration of their competitive advantage. This rush of capital into a given industry eventually culminates in cutthroat competition that sometimes can engender high levels of innovation and the rapid expansion of manufacturing. As a result, China has experienced negative returns on capital and market inefficiencies alongside impressive expansions in market share and growing economies of scale. These trends create two challenges which are persistent in China's techno-innovation model: First, persistent low margins for companies can undermine long-term investment in R&D and future innovation as well as domestic employment (the "involution" challenge). Second, these very same dynamics are driving Chinese companies to seek new markets abroad, creating new trade tensions and in some cases backlash, such as with EVs, which are facing increasing tariffs globally, including in Europe.

Factor markets have shifted from low-cost labor toward more engineering and skilled trades, with unevenness across regions and tiers. China graduates large STEM cohorts, including the world's most science and engineering PhD students (creating education supply before demand pull), and has the world's largest installed base of factory robots, which eliminates low-skill jobs.[75] Simultaneously, major rural-urban education gaps persist, and broad but variable vocational training enrolling some 17 million students creates bottlenecks in technician pipelines that matter for high-tolerance manufacturing.[76] This mix favors superior performance in low- and medium-tier technology tranches while constraining precision manufacturing niches.

Physical and digital infrastructure remains a significant competitive asset, although unevenly distributed. China has shown spectacular capacity to build high-speed rail, airports, fiber-optics, long-distance electricity distribution, and near-ubiquitous 5G, with over 4.65 million 5G base stations installed.[77] Strong infrastructure lowers costs for existing and new industries and allows for rapid diffusion. However, China suffers from persistent inequality in the provision of most infrastructure, creating pockets of excellence and underdevelopment. For instance, internet penetration reached over 85 percent for urbanites, but only 64 percent in rural areas.[78]

Despite "self-reliance" rhetoric, international linkages are crucial to maintaining domestic capabilities if China wishes to pursue the leading edge. China still remains highly engaged in global trade, investment, joint research, and standards bodies, which continue to connect Chinese firms to global knowledge networks and foreign technologies and markets. Thus far, China's pragmatism concerning foreign technology has trumped its desire for self-sufficiency whenever foreign technology is critical. Furthermore, China has continued to expand its investment and business alliances, particularly in Southeast Asia and the Global South more generally.

Technology-Specific Ecosystems

STACK TECHNOLOGIES: STRONGER LAYERS COMPENSATE THE WEAK

China demonstrates a paradox. It dominates low- and medium-tier Base technologies, has had trouble breaking into high-end and Precision manufacturing technologies, and yet has achieved relative parity with the United States in AI—an industry of great complexity. Furthermore, it does so with a major handicap on compute thanks to U.S. export controls on advanced AI accelerators. In 2024, China produced fewer top models than the United States, but the ones it did release performed exceptionally well on a diverse set of well-regarded benchmarks.[79] China's top model achieved near parity with U.S. models, consistently scoring only 0.2 percent to 8.1 percent lower on five different benchmarks that cover both math-based and language-based tests.[80]

Unlike sectors such as jet engines, China's AI firms are privately owned and populated by well-trained entrepreneurs and top staff with international experience. Companies with this kind of profile tend to be the most dynamic in China, in stark contrast with SOEs. These include the giant platforms of China's leading tech firms: Baidu (ERNIE), Alibaba (Qwen), Tencent (Hunyuan), ByteDance (Doubao), Huawei (Pangu), and DeepSeek, among other smaller ones. However, the United States has more major AI labs, and each one releases more product lines and versions. By contrast, Chinese labs are often of very high quality but are fewer in number and typically have only one main general-purpose line with several domain variants.[81]

Unlike sectors such as jet engines, China's AI firms are privately owned and populated by well-trained entrepreneurs and top staff with international experience.

U.S. export controls have handicapped all Chinese labs by restricting U.S. and foreign firms alike from shipping advanced logic and memory chips to China. This hardware barrier restricts China's buildout of hyperscale data centers. Despite having leading models, China only has about 15 percent of the world's AI accelerator computational performance in early 2025, whereas the United States dominates nearly three-quarters.[82] This is reflected by the fact that China has built only 16 percent of hyperscale data centers globally, whereas the United States is responsible for over 50 percent.[83] Without the compute constraints that flow from U.S. restrictions, China certainly has the capacity to build out massive infrastructure such as data centers. Furthermore, China's energy buildout positions the country well to supply the massive energy needs of AI. The International Energy Agency estimates that China invested $88 billion in electricity transmission and distribution in 2025.[84] On generation, the growth of clean energy sources is particularly notable. China's expansion outpaced growth in electricity demand in the first half of 2025 and met over 80 percent of demand growth in 2024.[85] Yet, China's growing electricity demand, which is still primarily driven by factors other than data centers but could grow further as investment in AI ramps up, means that the country will continue to need record new installations as well as improvements to the energy market to ensure stable and affordable energy. Although well positioned to succeed in this goal, it remains a daunting task.

Chinese labs achieve parity through other layers in the stack that are more software-based, including algorithmic efficiency; leveraging open-source software resources (and contributing to them), which is based on a large pool of well-trained talent; basic research (publications); and IP. These factors were all evident in DeepSeek's release of R1, which shocked the world with its apparent performance capabilities and cheap training costs, which many attributed to innovative software engineering, making up for China's limited compute. China's talented software engineers create innovative software efficiencies, train models on high-quality data, rely on open-source ecosystems to acquire know-how, create strong training recipes, and focus limited compute on a small number of well-engineered training runs.

China also produces many AI scientists: 26 percent of the world's top 2 percent of AI scientists come from China, with the United States at 28 percent.[86] Yet, many more Chinese scientists end up working for U.S. firms than vice versa. Indeed, 47 percent of the top 20 percent of AI scientists globally in 2022 originated from China.[87]

Apart from building models, China has been exceptional at deploying them, which partly derives from state-led policies. The AI Plus initiative, which has similarities with the 2015 Internet Plus initiative aimed at promoting the digital economy, is explicitly aimed at introducing the use of AI across the economy to enhance productivity for those industries and, in turn, upgrade AI tools as they acquire more data.[88] China's huge pool of AI scientists will accelerate this. At the same time, advanced hardware tech firms like iFlyTek, SenseTime, and DJI are actively seeking to integrate AI into their products. Government procurement also plays a role here. For example, the extensive demand for surveillance technology by local governments in China has been found to correlate with later improvements in companies' commercial performance.[89] Finally, the fact that many Chinese models are open-source has made them particularly popular inside and outside of China, increasing their reach and impact globally.

PRECISION TECHNOLOGIES: COMMERCIAL JET ENGINES

China has invested extensive resources over almost five decades to develop its own commercial jetliner and jet engines, but thus far it has little to show for it.[90] There is plenty of capital and political will behind commercial aerospace in China. For instance, the country has poured tremendous capital into the industry, including about $15 billion through the "Two Engines" program in 2016.[91] Furthermore, Chinese leaders have personally interceded to promote and encourage the industry, given national security interests and the national prestige of joining the very small group of companies and countries capable of operating at the cutting edge. Although the Commercial Aircraft Corporation of China (COMAC) has achieved some success, with the regional C909 (originally known as the ARJ21) and narrow-body C919 now in production and operation, China still finds itself very far behind the United States and Europe on both commercial aircraft and its most important component, the jet engine.[92] The development of both planes was delayed by several years, and both are technically inferior to competing options produced by Embraer, Bombardier, Airbus, and Boeing.

China's aviation sector has missed every single timeline target it has ever set.

Critically, all of the key components of both planes, including the engine, are sourced from Western suppliers. China has tried unsuccessfully to pilfer engine technology, most notably gas and steam turbine technology from General Electric.[93] In the last decade, it has also expanded efforts to create its own engine. The Aero Engine Corporation of China (AECC), founded in 2016 and initially injected with $7.5 billion, has made some technical progress on its CJ-1000 turbofan engine, but it is still in development and far from being able to replace the Leap-1C produced by CFM International (a U.S.-EU joint venture) that is used by COMAC.[94] Thus, as of today, there is not a single Chinese engine in commercial flight, even within China. News reports suggest China is aiming for the CJ-1000 to be certified in the next two years and be available for commercial use by 2030, but China's aviation sector has missed every single timeline target it has ever set.[95]

The proximate reason for the lack of progress in this area in China is that these are extremely complex technologies. Excellence does not just rely on patents and R&D, but also on the tacit manufacturing knowledge and trade secrets gained by engineering teams over decades, such as understanding how the metallurgy and machining of engine blades are affected when operating at ultra-high temperatures in high-altitude conditions. As a result of extraordinary safety concerns, incremental improvements are less acceptable in engine technology than other industries.

However, experience and knowledge are derived from deep network partnerships between companies and the sharing of information derived from in-flight operations. Since no Chinese engines are in flight, there is no data generation feeding into the Chinese supplier ecosystem for manufacturers to learn from and improve continuously. Also, without flying engines, there are no revenue streams from maintenance and repair (which constitutes up to 90 percent of revenue for engine makers), nor are there the long-term contracts between operators and engine companies that fund current development and next-generation research.[96] These positive feedback loops cannot get off the ground.

Consistent with the discussion about enterprise strategies, China is at a significant disadvantage with SOEs such as COMAC and AECC leading the charge. Both emerged out of the Aviation Industry Corporation of China (AVIC), which is closely tied to the People's Liberation Army (PLA) Air Force. SOEs are highly bureaucratic, have low internal transparency, and avoid genuinely deep collaborations with foreign partners. The leaders of China's commercial aviation sector are a universe away from the companies leading China's innovation progress in other industries. Given that this circumstance is unlikely to change any time soon, the centrality of SOEs will continue to hamper China's efforts to improve its competitiveness in jet engines.

Finally, the level of technology sharing between Western and Chinese firms has been much less than in other industries. Western leaders have fiercely protected their technology, and Chinese airlines have happily purchased Western planes and not been enthusiastic about switching to alternative domestic suppliers. AECC's links to the Chinese military as an SOE have also hamstrung it. The U.S. government placed AECC on the Bureau of Industry and Security's Entity List in 2020, and many components are export controlled. This makes sales and collaboration impossible and the road to take off that much longer.[97]

PRODUCTION TECHNOLOGIES: MACHINE TOOLS—SUPPLIER DEPTH AND LEARNING CURVES

Beijing has long targeted machine tools, but its support has had limited impact. As the workshop for the world, China has long treated the high-end machine tool industry as strategic. It was designated as a National Major S&T Project in 2006 and prioritized in the 11th Five Year Plan, published in 2007. Later, it was placed toward the top of the Made in China 2025 priority list, with sector-specific plans continuing into the 14th Five-Year Plan, published in 2021.[98] However, despite consistent support, results have been mixed. On the one hand, China is now the largest overall producer of machine tools, with a market value exceeding RMB 200 billion ($28 billion).[99] On the other, China's domestic players remain largely in low and medium segments.[100] Furthermore, unlike in other industries, China became a net exporter very late, in 2021, and has captured only smaller global market shares, with some exports deriving from foreign companies producing in China. China is not an export juggernaut in machine tools as it is in other industries.

Part of the reason for this shortfall is that, compared with headline sectors like semiconductors, EVs, and next-generation IT, the intensity and continuity of financial support for machine tools have been more modest and episodic. Local subsidies surged with the 11th Five-Year Plan but later contracted amid fiscal stress and shifting priorities, contributing to bankruptcies and consolidation even as China still relies heavily on foreign suppliers for the highest-end equipment. The industry in China is composed of small and medium-sized enterprises with relatively small revenue streams, meaning that leading firms can be constrained in terms of capital and have limited funds for R&D.[101] Moreover, because of the nature of the technology in the most cutting-edge segments, leading firms are less likely to benefit from the types of economies of scale that have enabled Chinese firms to capitalize on government subsidies in other sectors.[102]

Chinese firms capture about one-third of total global production, but they are concentrated at the low and medium tiers of machine tools and are mostly for domestic sales, where customers are most concerned about total cost, including factors like uptime, reliability, and maintenance.[103] In these segments, producers can also rely on general platforms, unlike in higher-tier segments that demand advanced customization. Domestic Chinese suppliers have a strong market position in general-purpose turning, milling, and machining centers, where incremental improvements and cost discipline matter most. Furthermore, with its massive industrial base, Chinese machine tool OEMs have direct access to a diversity of auto, appliance, and component manufacturers, which supports expanded utilization across differing environments and improves yield learning. Their local knowledge is also critical for maintenance response times, serviceability, and compatible tooling ecosystems, which often outweigh the importance of high-end, micron-level tolerances in most industries. Thus, Chinese firms can offer good-enough quality at a low total cost in low and medium tiers.

However, the key barrier to Chinese firms upgrading to high-end and ultra-precision tools, such as CNC precision tools, is an inability to break into dense networks of suppliers, assemblers, and end-use customers built upon long-term, trusted relationships. As discussed in Chapter 4, at the high end, competitive advantage rests on deep collaboration across the value chain, including customizing machines and operations for particular customers and even particular factory shopfloors; precision, customizability, reliability, and durability are central—not price. These goals are achieved through very tight coupling of subsystems between suppliers (e.g., metrology and controllers) and with customers, sometimes coordinated through banks.[104] This is why the industry is tightly clustered in Germany and Japan, where partnerships are longstanding.[105] Furthermore, to achieve customization, some end-use customers also become strategic partners and provide vast streams of proprietary data to their machine tool suppliers for constant recalibration and iterative customization.[106] As a result, the primary barrier for Chinese firms is breaking into these tight, multitiered, and trusted networks, or creating their own.[107] Without such a change, they have no access to the positive feedback loops that enable iterative improvements to their products or the ability to customize and build long-term customer relationships. Finally, many high-end machine tools are dual-use technologies listed in the Wassenaar Agreement because they can be used in technology with military applications, such as missiles, jet engines, and nuclear components. Export restrictions on such technology include "knowledge" transfers between engineers. This mandated restriction on technological diffusion, combined with reticence to share technology on the part of established firms, has limited technology transfers to Chinese firms.

Skills training is a second critical deficit in China, which is partly tied to its lack of top-tier companies. Specialized skills are needed for both shopfloor talent within machine tool companies and to install, recalibrate, and service machines for their customers. China has an enormous vocational training system, but quality is low because the social status of such jobs is inferior to attending university, and training is heavily tilted toward book learning and exams rather than hands-on skills cultivation.[108] This produces a sea of competent graduates, but without tacit knowledge or sufficient dedication to machining, creating a fluid labor market. By contrast, Japanese training has traditionally been heavily company-specific and based on mentor-apprentice relationships, and comes with lifetime employment, substantially reducing labor mobility.[109] Germany is mixed, with three-year specialized degrees that are both hands-on and transferable across companies, along with in-house training at top companies.[110] In both Japan and Germany, and because of their domination of the industry, trainees get regular hands-on access to top-of-the-line five-axis and ultra-precision machines. This is particularly important for the in-field engineers who work directly with the company, where Japan and Germany shine.

Looking forward, China will continue to make high-end machine tools a top priority—indeed, they are mentioned as a target industry in the 15th Five Year Plan's recommendations, but both the incentives and ingredients for success may not be in place.[111] Because precision tools are needed in advanced manufacturing, they are a critical area for China's continued efforts to indigenize technological production and innovation. Furthermore, as factories are retooled for Industry 4.0—a top priority in China—high-end machine tool companies will be leading players of these integrated systems. As a result, Beijing will continue to target the sector. As discussed, however, the positive feedback loops between companies and between labor and companies are difficult to create, keeping Chinese firms at a persistent disadvantage. Furthermore, China's playbook of trading technology for market access has not proven effective, partly because of the "stickiness" of these industrial clusters and the difficulty of transferring the accumulated knowledge. Just as importantly, export controls and resistance on the part of established firms will continue to limit technology transfers which could facilitate upgrading.

BASE TECHNOLOGIES: RARE EARTHS AND ADJACENT INPUTS

The primary driver of China's domination of rare earth mining, processing, and metal and magnet production is its decades of industrial policies. After years of illegal mining and processing by local governments, Beijing introduced production and export quotas, pursued several rounds of forced industry consolidations that concentrated the industry into the hands of a few SOEs, and most recently introduced export controls that limit international diffusion.[112]

For years, local governments abetted and benefited from illegal mining, processing, and export smuggling, but Beijing has since been able to consolidate the industry, which gives it control and leverage. After smugglers undermined the government's attempt in 2010 to discipline Japan by restricting rare earth exports, the State Council intensified campaigns to close down illegal mines and factories by directing quota licenses to select local mines.[113] Mining and export licenses were halved, but 90 percent were doled out to preferred local mines, which eventually became consolidated into the Big Six rare earth companies.[114] By 2012, 35 northern companies were consolidated into China Northern Rare Earth Group, and by 2016, hundreds of southern mines were consolidated into five heavy REE companies.[115] From 2021 to 2024, these five firms were further consolidated, leaving China with just two rare earth conglomerates: the previously mentioned China Northern Rare Earth Group and the more recently established China Rare Earth Group.

The primary driver of China's domination of rare earth mining, processing, and metal and magnet production is its decades of industrial policies.

Industrial policies work together to control market forces and prices and achieve full-chain mine-to-magnet integration. REEs are a mass-scale, capital-intensive, and low-margin industry, making maximal machinery utilization critical. As such, the flow of material quantities and quality grades through the chain must be stabilized to prevent machines from being idled or requiring recalibration. To achieve this, China introduced semiannual production and export quotas in 2006, as well as licensing regimes for mining and processing.[116] Starting in mid-2023, China has begun to impose export controls on rare earth products as well as related machinery and tools.[117] In combination, these industrial policies improved efficiencies and quality levels but also allow China to exert coercive control over global supplies, evidenced by the effectiveness of its export restrictions in 2025 compared to 2010.

A second critical factor is China's genuine innovations through the build-up of know-how in rare earth properties, applications, and chemical processing. For instance, chemical solvent extraction (to separate REEs) remains technically complex, often requiring hundreds of solvent extraction stages and a delicate balance of chemical processes.

What differentiates China is its degree of scientific and educational specialization on rare earths. China has three key state labs that specialize only in rare earths and numerous degree-granting universities that specialize in rare earths. In both the Inner Mongolia (Baotou) and Jiangxi (Ganzhou) clusters, there are science and technology universities that have entire colleges dedicated to rare earths that grant undergraduate and graduate degrees, as well as scores of vocational colleges with specialized rare earth majors.[118] China also publishes all four scientific journals that specialize in rare earths, two of which are published in English.

A Realistic Balance Sheet

Although complex, China's competitive successes and failures show some distinct patterns, which offer important clues to U.S. businesses and policymakers. Beijing excels where patient capital, vertical integration, process knowledge, and scale-driven learning compound, such as in rare earths and batteries. However, it struggles where highly complex technologies are guarded by trade secrets and reliant on incremental innovation with low economies of scale, as well as where long-term, tight-knit, and trust-based networks create "innovation clubs" that serve as durable moats, such as in jet engines and ultra-precision machine tools. These problems are magnified in sectors dominated by SOEs, which are particularly poor at trust-based cooperation.

Nevertheless, China's gains reflect genuine capabilities and a powerful innovation ecosystem beyond IP theft. It wields manufacturing scale, high learning rates, and supplier depth built through a hybrid model that combines state direction with local competition. Beijing can deploy deep pockets to subsidize firms and create markets, yet success depends on a variety of technology- or firm-dependent factors. In some instances, China has struggled to engineer the collaborative partnerships that underpin Precision technology leadership. Where China leverages software innovation to offset hardware constraints, as in AI, it achieves near-parity, at least for now. Where advantage rests on learning loops and multidecade relationships, progress stalls even despite massive investments. These patterns reveal where the West holds defensible advantages in the global technology competition.

7

America's Technology Position

Inherited Strengths, Mounting Challenges

The United States faces unprecedented national security and economic competitiveness challenges in the twenty-first century. The competitive landscape is fundamentally different than it has been in the past three generations. While U.S. research and production networks now span the globe, China has emerged as a scientific near peer that has invested heavily in domestic industrial infrastructure over decades. Unlike the Soviet Union, China's innovation networks are deeply interwoven with those of the United States and many other countries.[119] This interdependence creates new economic security vulnerabilities.

At present, U.S. innovation strategy continues to rely on a seven-decade-old strategic playbook that was designed to address the challenges of the Cold War. That strategy, set in motion by Vannevar Bush, envisioned innovation happening along a neat, sequential pipeline.[120] The federal government would fund basic research, primarily through universities, while leaving experimental development and commercialization to the private sector.[121] This strategy made sense at that time: The United States was a major manufacturing power, having scaled up for the war effort, but needed to boost its upstream R&D infrastructure.

Over the past three decades, the U.S. manufacturing base has steadily eroded while research, development, and production networks have grown more complex and global in scope.

However, this linear model assumed the entire innovation pipeline would remain predominantly domestic. Instead, over the past three decades, the U.S. manufacturing base has steadily eroded while research, development, and production networks have grown more complex and global in scope.[122] Although upstream research has remained strong, structural economic forces, including increased financialization and an overvalued dollar (See Box 7.1), have incentivized offshoring, hollowing out the "missing middle"—where capital-intensive engineering, testing, and manufacturing infrastructure helps support middle-class wages, and where technologies prove commercial viability through iterative failure and learning-by-doing. This has been particularly detrimental to scaling up high-complexity technologies where steep learning curves require sustained investment that only large OEMs or state-backed competitors can shoulder. Meanwhile, related investments in workforce training, energy infrastructure modernization, and inter-firm and public-private partnerships have withered.

Recently, successive presidential administrations and Congress have recognized the limitations of this strategy. The longstanding political consensus that dismissed industrial policy as harmful market interference is shifting. This is reflected both in Biden administration policy initiatives, such as the CHIPS and Science Act and the Inflation Reduction Act, along with recent moves by the Trump administration, such as taking an equity stake in Intel.[123] As the United States reengages with industrial policy, it must confront the result of the past seven decades of its technology strategy: It retains leadership in research but holds a decaying "industrial commons" which is needed to scale new technologies and capture first-mover advantage.

Economy-Wide Fundamentals

Traditional U.S. strengths relied on key building blocks: macroeconomic stability, institutional predictability, deep capital markets, substantial and sustained investments in science, and an immigration system that drew in the world's best minds. Today, most of these fundamentals are under threat, amplified by political polarization, expansion of executive power, growing national debt, and a surge in economic policy uncertainty. Macroeconomic stability, anchored by an independent Federal Reserve, has historically given U.S. firms planning certainty—but political pressures now threaten this advantage.[124] Strong rule of law and regulatory quality have lowered transaction costs, but polarization and executive power expansion are eroding these institutional advantages.[125]

Deep capital markets remain a strategic asset, but patient capital for long-horizon manufacturing projects remains scarce.

Deep capital markets remain a strategic asset, but patient capital for long-horizon manufacturing projects remains scarce. This leaves the United States well-suited for disruptive software innovation but poorly equipped for advanced, capital-intensive manufacturing like machine tools or low-margin Base technologies like rare earths. As a result, the U.S. innovation system has shifted from one of significant strength to one that is more vulnerable, particularly in its manufacturing base and, increasingly, even in basic science. During the era of globalization, the United States' institutional and financial strengths masked these weaknesses to some extent. However, the long-term hollowing out of the manufacturing base has undermined U.S. competitiveness in many critical industries and opened the country up to new economic security threats.

BOX 7.1

The Dollar and the Erosion of U.S. Industrial Competitiveness

The erosion of U.S. export competitiveness can also be attributed to broader macroeconomic forces, though the exact mechanics continue to be hotly debated. Some economists blame the persistent strength of the U.S. dollar, arguing that the world's inelastic demand for dollar assets–sustained by the dollar's reserve status and the attractiveness of the U.S. economy–has priced U.S. manufacturers out of global markets.[126]

Others have emphasized a deeper driver behind trade imbalances: the United States' persistent savings imbalance.[127] When U.S. residents spend more money than the economy earns–a dynamic increasingly fueled by fiscal deficits–foreign capital from surplus countries like China must fill the gap.[128] This translates into a negative trade balance for the United States.

Several policy remedies have been proposed. These include policies that would discourage U.S. consumption and increase savings, capital inflow restrictions, or even coordinated central bank action through "Plaza Accord-style" arrangements, recalling the 1985 effort by major economies to weaken the dollar.[129] While some view the Plaza Accord as a generally successful case of central bank intervention, others contend its effects have been overstated.[130]

While the question of how to reduce trade imbalances will remain a salient policy and political issue for the foreseeable future, unwinding them–whatever the policy mix–would likely take several years and require significant international coordination.[131] In the meantime, the United States need not wait to invest in the microeconomic drivers of industrial competitiveness–building dexterity across acceleration technologies and the technologies that support them.

The weakening of the U.S. manufacturing base has been driven by a number of structural drivers. Capital markets, tax incentives, and the logic of comparative advantage have pushed U.S. firms to specialize in capital-light, high-margin activities such as R&D and design while offshoring production that requires high capital expenditure and produces at low margins. In the short term, these choices boosted efficiency and shareholder value. But over time, they fractured the tight linkages between design, engineering, and manufacturing that traditionally fueled U.S.

technological leadership.[132] In today's environment, that strategy has become a liability. The geographic separation of production from R&D has undermined inter-firm partnerships, thereby weakening feedback loops, slowing iteration cycles, and eroding tacit production knowledge within U.S. industry. It has also left the United States more vulnerable to unreliable global supply chains (as seen during Covid-19), along with economic coercion, as seen with rare earths. Meanwhile, competitors—most prominently China—utilize patient capital and tolerance for negative margins to scale manufacturing rapidly and to export at low prices.

U.S. leadership in R&D for basic science—a legacy of long decades of sustained public investment in science—is also now under strain. Although private R&D spending outweighs public outlays, federally funded R&D has declined as a percentage of GDP at a time when other countries are increasing public research budgets.[133] U.S. leadership in science has also long served as a magnet for researchers and students to come to the United States and contribute to the U.S. innovation ecosystem. Recent cuts to the nation's premier science agencies, political oversight over research agendas, and uncertainty about U.S. immigration policies now threaten this hard-earned advantage.[134]

Technology-Specific Drivers

Technology-agnostic economic and institutional strengths are necessary—but not sufficient—in today's strategic technology competition. Each industry and each innovation require the interlinking of different combinations of ecosystem elements to bear fruit, whether industrial or other policies, resource streams, foreign partnerships, business alliances, or security guarantees.

STACK TECHNOLOGIES: STRONGER LAYERS COMPENSATE THE WEAK

AI represents the pinnacle of U.S. technological leadership because U.S. firms have evolved complex ecosystems of Stack technologies, dominating most layers and developing the interface standards between layers. The United States is home to leading firms across the AI stack, including chip designers, frontier labs, open-source resources, software platforms (like NVIDIA's dominant CUDA), software frameworks and libraries, and a thriving startup culture built around using AI tools. These outcomes reflect the United States' long-standing advantages in fostering Stack technologies: a deep pool of risk-tolerant capital, a vibrant research ecosystem, and firm strategies that prize establishing first-mover advantage and setting standards through scalable digital platforms.

U.S. firms dominate chip design but remain dependent on TSMC for production. Together, NVIDIA and AMD occupy more than 90 percent of the market for the advanced GPUs that have enabled the modern AI revolution.[135] The United States has nearly three-quarters of AI computational capacity installed at home, demonstrating a commanding lead in chip design and networking hardware. But this lead does not extend to chip manufacturing, where U.S. design firms remain reliant on foreign manufacturers, especially Taiwan's TSMC for logic and South Korea's Samsung and SK Hynix for memory. In partnership with TSMC, progress is being made to increase U.S. production.[136] With CHIPS and Science Act programming, and now tariffs on semiconductor imports, the United States has established a more active industrial policy to foster domestic production of leading chips.

The United States maintains strong leadership in AI model development. In 2024, leading AI labs produced 40 notable AI models, well ahead of China's 15 and Europe's 3.[137] While Chinese models still lag U.S. equivalents, they are not significantly behind, and the pace of change is unpredictable.[138] The trendlines over time show China consistently narrowing the gap.

U.S. companies hold a dominant share of the AI market, and the United States has a strong position in AI-enabled software. However, the country lags in other edge applications.[139] Adoption rates are extraordinarily hard to measure, but it seems clear that diffusion is not keeping pace with the astronomical scope of investment. Furthermore, uptake appears concentrated in the tech, scientific, educational, and real estate sectors, but is much less robust in healthcare, construction, and manufacturing. There are clear roles for both specific enabling policy and ecosystem governance to be applied to sectors where uptake is lagging.

Economy-wide factors have played a crucial role in developing these strengths. The United States benefits from deep capital markets, a permissive regulatory environment, and a first-mover tech culture that prizes rapid experimentation and scale. Clusters in regions such as Northern Virginia and Silicon Valley—where high-capacity networks, talent pools, and server farms co-locate—have reinforced this edge. However, that environment is increasingly constrained by aging infrastructure and energy bottlenecks.

U.S. strength also stems from enterprise strategies that have aggressively pursued vertical integration across the AI stack. Leading U.S. tech firms have preferred to build proprietary models, design custom chips, and operate dedicated cloud infrastructure. This gives the United States a durable advantage in model deployment and inference, although the open-source race remains an open question. At the same time, some U.S. firms have moved quickly to commercialize AI across sectors, from life sciences to defense. Still, not all firm strategies are aligned with national objectives. High concentration in frontier model development and rising costs of compute and energy raise concerns about resilience, competition, and diffusion. Moreover, limitations in workforce availability—particularly for engineering, data science, and advanced energy deployment—pose growing risks.

While industry-led dynamism is a U.S. strength, long-term leadership in AI also requires robust technology enablers.

While industry-led dynamism is a U.S. strength, long-term leadership in AI also requires robust technology enablers. Here, the picture is more mixed. Federal R&D investments in AI remain relatively modest and fragmented across agencies, and are significantly outpaced by private investments.[140] IP frameworks for AI-generated content and models are underdeveloped, creating legal uncertainty and resulting in U.S. inventors capturing only 14 percent of AI patents (compared to China's 70 percent).[141] The United States is strong in international standards participation—particularly through its firms—but lacks a coordinated government strategy to shape technical and ethical norms.[142] Immigration bottlenecks and lagging STEM education funding limit the workforce pipeline, even though the United States employs 57 percent of the top 2 percent of leading AI scientists.[143] Critically, the United States also lacks sustained mechanisms to help emerging firms cross the valley of death—from early-stage seed capital to growth-stage scaling.

Power availability is becoming a bottleneck for deploying compute in the United States. The U.S. power grid has grown slowly over the past two decades. But plans for large investments in data centers to power generative AI now imply rapid growth that will more than double current power demand by 2030.[144] Meeting that demand growth will require building new power plants and adding new power generation capacity, which is a process that takes years of regulatory approval. Delays in empowering data centers are slowing development in regions already crowded with compute infrastructure, such as in Northern Virginia, and rising electricity prices threaten to foment local political resistance to new data center construction.[145]

Precision Technologies: Commercial Jet Engines

Jet engines represent one of the clearest cases of enduring U.S. technological leadership. In commercial markets, U.S. firms together account for more than four-fifths of global sales, and they dominate the design and integration of military propulsion systems.[146] As high-complexity, special-purpose technologies, jet engines are capital-intensive, require mastery of advanced materials and supply chains, and must perform reliably under extreme thermal and mechanical stresses. What distinguishes the United States is that its institutions and firms have built an ecosystem in which regulation, government R&D, procurement policy, and inter-firm learning generate cumulative advantages that are exceptionally difficult to replicate.[147]

The primary driver of U.S. leadership lies in ecosystem governance—how firms, regulators, suppliers, and airlines interact in tightly coupled feedback loops. Unlike open innovation systems where ideas flow broadly, jet engine innovation is confined to a relatively small circle of certified players. Within this circle, however, learning is deep.[148] Airlines supply operational data, suppliers co-develop critical subsystems, and regulators oversee incremental upgrades. Certification itself produces vast amounts of validated performance data, which firms feed back into design improvements. Over time, this closed loop has created a path-dependent system in which each cycle of certification and feedback not only makes engines safer but also deepens U.S. technological leadership.

Federal Aviation Administration (FAA) certification creates both a trust premium and barriers simultaneously—only firms that can afford decade-long validation cycles and billions in development costs survive, concentrating knowledge among incumbents. Meeting FAA standards requires years of testing, validation, and documentation.[149] While costly, this process creates a

Each cycle of certification and feedback not only makes engines safer but also deepens U.S. technological leadership.

global gold standard: airlines and defense customers worldwide adopt U.S. engines because FAA certification signals unmatched safety and reliability. The industry's complexity magnifies this effect. Next-generation jet engines cost as much as $10 billion to develop, meaning entry barriers to the industry are extraordinarily high.[150] Long-term maintenance contracts generate decades of operational data that flow back into next-generation designs, creating cumulative advantages that rivals struggle to match.

Defense R&D and procurement have amplified these advantages. The Department of Defense, NASA, and the Department of Energy have invested consistently in propulsion research, enabling U.S. firms to operate at the technological frontier.[151] Defense acquisitions have helped maintain the industrial base by sustaining demand for new propulsion systems, ensuring that firms retain the scale, supplier relationships, and workforce needed for leadership.[152] The dual-use structure has been critical to success: Military programs stretch the technological frontier, while commercial revenues stabilize balance sheets and amortize costs.

U.S. enterprise strategies have reinforced these systemic advantages. The dual-use orientation of GE and Pratt & Whitney has enabled them to cross-subsidize between commercial and defense programs, maintaining industrial scale while pursuing frontier performance. Heavy industry consolidation has reduced competition, but it has also concentrated expertise in firms capable of sustaining billion-dollar R&D programs. The U.S. talent pipeline is another differentiating factor. Top U.S. aerospace programs graduate thousands of engineers annually (over 8,500 in 2023), feeding both prime contractors and the supplier base.[153] This steady inflow of specialized talent ensures that the U.S. ecosystem has the expertise to push materials science, computational modeling, and testing infrastructure further than most rivals.

PRODUCTION TECHNOLOGIES: MACHINE TOOLS—SUPPLIER DEPTH AND LEARNING CURVES

The United States was initially the pioneer in high-end machine tools. It first developed numerical control (NC) technology, which was a key breakthrough in the mid-twentieth century that automated machining operations by encoding machine instructions.[154] Even as of 1980, after decades of diffusion, the United States was "the largest producer of machine tools, with 20 percent of the world market."[155]

As the U.S. high-end machine tools industry has declined, other nations have taken on a dominant role.

Nonetheless, the United States experienced a sharp decline in its high-end machine tools industry, as the country shifted "from being a net exporter to being the world's largest importer of machine tools" from 1975 to 1985.[156] Today, U.S. firms compete in the mid-tier and are focused on specialized high-end machine tools, including aerospace and defense, where federal government demand is supportive.[157] As the U.S. high-end machine tools has declined, other nations have taken on a dominant role: Germany and Japan dominate high-end machine tools, while China is the largest producer in the low- and medium-tier segments.[158]

There are several key underlying drivers that account for the rise of these three other nations and the decline of the United States. German and Japanese firms dominate high-end production because of enterprise strategies, especially extensive supply chains and dense networks between key players in the ecosystem, including component suppliers, OEMs, and end users. These business networks enable collaboration, iterative improvement, and standardized processes and systems. OEMs can lock in their customers by using custom designs and molds, making customers—who tend to value quality and reliability over price—hesitant to take the risk of changing suppliers. This lock-in generates trust and allows the sharing of anonymized factory data across the supply chain.

Financial systems are another key factor determining the prospects of the high-end machine tools industry. Specifically, Germany and Japan have bank-based financial systems that offer patient capital, which rewards long-term planning and outcomes and builds lasting relationships across stakeholders.[159] By contrast, the U.S. financial system is fit-for-purpose in funding disruptive innovations that create large, short-term gains; however, it struggles to serve industries—such as high-end machine tools—that are long-term, capital-intensive, and require continuous improvement and incremental gains.

Another critical driver relates to workforce training, which is crucial in advanced manufacturing. Germany's related programs consist of three or more years of very specialized vocational training in machine tools and in-house company training, while Japan relies more heavily on company-specific master-apprentice training and lifetime employment.[160] Given the prevalence of ultra-precision machines, trainees in both countries have regular access to the most advanced machines. By contrast, U.S. companies offer far inferior and shorter in-house training programs, and vocational training is more generalist and book-based learning.

In terms of the U.S. government response, the Department of Defense has recognized these challenges in areas of the defense sector and has attempted to address them through the Industrial Base Analysis and Sustainment (IBAS) Program, which is intended to address supply chain vulnerabilities and bolster defense manufacturing sectors.[161] This is a helpful effort to address weaknesses in the defense industrial base, but it is insufficient to address the underlying shortcomings discussed above.

BASE TECHNOLOGIES: RARE EARTHS AND ADJACENT INPUTS

REEs should not represent the significant strategic vulnerability to U.S. technological leadership that they currently do. REEs are best understood as special-purpose technologies that have relatively narrow direct uses, yet are indispensable enablers of many critical downstream technologies, such as semiconductors, motors, and missiles. In the past few decades, the United States has lost technological leadership on rare earths to China due to broad economy-wide trends that have favored investment in other industries, failures in ecosystem governance, and China's ecosystem advantages and malign practices.[162] U.S. firms faced weak margins, complex permitting regimes, and growing competition from Chinese producers backed by state support and cost-insensitive capital.

Universities cut geology and metallurgy programs, companies stopped recruiting, and a generation of technical experts left the field, eroding the skilled workforce needed to maintain a domestic REE ecosystem.

The United States is utilizing heavy-handed policies . . . to rebuild governance and, eventually, capacity.

Recognizing this vulnerability, the United States is utilizing heavy-handed policies (for the United States) to rebuild governance and, eventually, capacity. The federal government has increased its REE R&D funding in the past decade, while federal agencies such as the Department of Energy, Department of the Interior, and U.S. Geological Survey are directing billions toward developing new mining, processing, and manufacturing technologies, including novel extraction methods and recycling capabilities.[163] After decades of neglect, the Department of Defense recently became the largest shareholder in MP Materials by investing $400 million to expand domestic mining and processing leveraging authorities under the Defense Production Act, as outlined in a March 2025 executive order.[164] It also established price floors for its products and guaranteed procurement for 100 percent of its output.[165] This deal illustrates the kinds of contractual levers that federal agencies are using to secure onshore processing capacity and advance domestic supply chains. Critically, however, although these can provide supply security in the long run for public uses, it is not enough to protect U.S. private industry from China's economic coercion.[166]

Still, persistent vulnerabilities reflect economy-wide and enterprise limits. Building new mines in the United States takes an average of 29 years to go from discovery to production due to permitting, regulatory reviews, and local opposition.[167] Profit margins remain thin, limiting the availability of private capital. Meanwhile, the workforce shortage in REE-specific expertise persists, from researchers to factory workers.

Allied partnerships could supplement lost domestic leadership. With U.S. capacity constrained, allies have stepped in. Australia plans to triple REE oxide output between 2025 and 2027, while Japan has expanded refining.[168] These efforts are critical to building redundancy but still fall short, as most partners also rely on China for separation, refinement, and magnet production.

REEs illustrate a broader pattern: For Base technologies, the United States struggles to close gaps without strategic governance, skilled labor, and sustained industrial policy. Rebuilding REE capabilities will require not just funding, but regulatory reform, public-private coordination, and targeted international partnerships.

Beyond Myths: America's Real Challenge

This chapter challenges the narrative of American decline while revealing execution challenges that can be addressed. The winner-take-all assumption fails: The United States excels in Stack and some Precision technologies, including AI systems, jet engines, and semiconductor design, thanks to factors like dynamic capital markets, top-tier talent absorption, and institutional trust. However, it has ceded leadership in Base and Production technologies, where factors like patient capital and incremental innovations determine outcomes. Legacy governance systems that are no longer fit for purpose, and a capital ecosystem that undervalues long-duration investment in physical assets has surrendered critical capabilities to competitors that compress deployment timelines through centralized coordination. Further, political polarization and underinvestment in infrastructure, research, and workforce development now threaten the foundations of areas where the United States retains advantages. Yet, the path forward is not autarky. It is coordination with allies like Germany and Japan to provide the production capabilities that the United States cannot rapidly rebuild. This path forward also requires building at speed and scale while preserving the openness and allied networks that have long defined the United States' decisive edge.

8

Partners in the Technology Long Game

Leverage Through Interdependence

The U.S.-China technology competition should be viewed as a contest of ecosystems, not just individual nations. While much analysis focuses on bilateral dynamics between Washington and Beijing, success in the long run will likely be determined by which side can more effectively mobilize global networks of innovation, production, and investment. Efficient supply chains require labor across many price points, global revenues to fund R&D at scale, and breakthrough innovations that emerge from international research networks. Therefore, the allied network is not only an ecosystem advantage but a strategic asset. This chapter illustrates how three major trading partners of both the United States and China—the European Union, South Korea, and India—currently offer advantages to U.S. and Chinese technology ecosystems.

The European Union: Production Excellence, Institutional Depth

STRATEGIC ADVANTAGES

The European Union represents just under one-sixth of the global economy and remains a critical partner for U.S. technology ecosystems, though this relationship has grown increasingly complex. Europe has positioned tech sovereignty at the center of its strategic agenda—an effort to reduce dependency on foreign suppliers across semiconductors, digital infrastructure, and critical raw materials, including through initiatives such as the EU Chips Act.[169] As with similar efforts being pursued in the United States and China, these pursuits come with significant trade-offs: higher costs, potential duplication of existing capabilities, the further erosion of the rules-based trading system, and the broader misallocation of scarce resources when structural challenges abound.

Europe had significant strengths in a broad set of strategic technologies. German, Italian, and Swiss firms produce high-end machine tools, advanced CNC machining, five-axis milling, and precision equipment.[170] China, the world's largest machine tool consumer, remains dependent on EU equipment for aerospace, medical devices, and advanced automotive despite Made in China 2025's independence efforts. In aerospace, Airbus competes directly with Boeing, while CFM International (a GE-Safran joint venture) operates as the world's largest jet engine supplier.[171] This transatlantic interdependence exempted aerospace from U.S.-EU tariff disputes.[172] Meanwhile, China's COMAC C919 remains dependent on Western engines, avionics, and materials.[173]

Despite these strengths, structural and macroeconomic headwinds hinder Europe's competitiveness. A shrinking working-age population and political resistance to immigration create labor constraints, while Russia's war of aggression against Ukraine has resulted in energy prices materially higher than the United States, raising production costs and straining fiscal capacity for necessary investments. Core bottlenecks include fragmented capital markets that force startups to seek U.S. venture capital, acute STEM skills shortages, and inadequate energy infrastructure. The 2023 Draghi report states that European startups face challenges raising late-stage capital at home and seek U.S. venture capital or listings to access deeper capital pools.[174]

INTEGRATION WITH THE UNITED STATES AND CHINA

Europe's linkages with the United States are exceptionally deep and fruitful for both economies. The transatlantic economy represents the world's largest bilateral relationship, with combined flows of over $7 trillion, accounting for nearly one-third of global GDP and almost half of global outward foreign direct investment.[175] U.S. companies generate over $300 billion annually in Europe, while European firms employ nearly 5 million U.S. workers.[176] The two economies are deeply integrated across defense industrial supply chains, space systems, semiconductors, and pharmaceuticals. Despite these deep and productive industrial and technological ties, tensions exist that limit cooperation. Recent U.S. actions have led many member states to reconsider the continent's significant reliance on the United States for its technological infrastructure and innovation.

Europe had significant strengths in a broad set of strategic technologies. . . . Despite these strengths, structural and macroeconomic headwinds hinder Europe's competitiveness.

Europe's economic relationship with China presents even more significant challenges and has evolved markedly in the last several years. China is the European Union's largest import source, at 21 percent of total imports, and its third-largest export market.[177] EU exports to China, valued at €213 billion ($247 billion) in 2024, are concentrated in automobiles, machinery, and luxury goods, while imports flow primarily in electronics, textiles, batteries, and critical raw materials.[178] As the Chinese market has become less welcoming to European firms and as China continues materially to support the Russian economy and war effort, the European Union has pivoted toward de-risking, with several European states restricting sensitive technology flows and tightening investment screening while working to fund domestic alternatives to Chinese production across multiple sectors.

STRATEGIC VULNERABILITIES AND PROTECTION MEASURES

To safeguard critical technologies and industries, the European Union has constructed a layered protective system, increasingly mirroring U.S. practices. Investment screening has emerged as a cornerstone since the EU-wide framework took effect in 2020, with more than 1,200 transactions undergoing review and dozens modified or blocked due to national security concerns.[179] A 2024 European Commission proposal seeks to mandate screening across all member states, harmonize procedures, and extend coverage to EU projects receiving public funding–reflecting mounting anxiety over Chinese acquisitions of semiconductor facilities, AI startups, and space-related assets.[180]

Under pressure from the United States, export controls have expanded significantly since 2022 to cover emerging technologies, including advanced lithography equipment, quantum components, AI accelerators, and legacy semiconductors.[181] These changes align the European Union more closely with U.S. controls on semiconductors and supercomputing technologies. European companies now face licensing requirements when exporting high-end semiconductor tools and supercomputer components to China, though member-state competencies create weaknesses in the overall regime.

Research security represents the newest and most politically sensitive protective measure. By 2024–25, national funding agencies and research organizations increased vetting or paused selected collaborations with certain foreign partners in sensitive fields amid concerns about espionage and IP protection.[182] These restrictions disproportionately affect dual-use fields such as AI, quantum computing, and aerospace.

A consistent challenge for the European Union is the delineation of competencies between member states and the European Commission, especially regarding security issues. Traditionally, matters like export controls, which are rooted in national security concerns, are considered a national competency. However, the free flow of goods within the European Union creates an obvious weakness in the bloc's regulatory regimes. It has made significant progress in centralizing many authorities now considered part of "economic security," but significant work remains to be done.

ILLUSTRATIVE CASES: HIGH-END MACHINE TOOLS

High-end machine tools exemplify Europe's comparative advantage in Production technologies. German, Italian, and Swiss firms (alongside Japanese and Taiwanese competitors) hold pole position in advanced equipment markets.[183] This is driven by dense networks of tight supplier-buyer relationships, apprenticeship programs producing skilled workers, and continuous process innovation across generations.[184] These advantages stem from generational expertise and customer co-development.

No single country—including the United States and China—leads in machine tools production. China produces volume in lower-tier categories, but it has yet to match European or Japanese performance in ultra-precision tiers. The United States ceded global leadership in the 1980s, although it retains significant market share. By working with its allies, it has also been successful in limiting adversaries' access (e.g., Russia's) to these critical industrial products.[185]

South Korea: Semiconductor Dominance, AI Ambitions

STRATEGIC ADVANTAGES

South Korea has positioned itself on the leading edge of critical technologies through world-class companies such as Samsung, SK Hynix, Hyundai, Naver, and LG Electronics. South Korea's technology sector combines dominant global players with a considerable startup ecosystem. Samsung and SK Hynix are global semiconductor leaders. SK Hynix, for example, holds over 50 percent of the high-bandwidth memory (HBM) market share critical for AI acceleration.[186] R&D investments are among the highest in the world, at an estimated 5 percent of GDP, driven mostly by the private sector.[187] South Korea also leads globally in years of schooling and boasts among the highest share of STEM degrees in tertiary education.[188]

The South Korean government has designated plans to promote a number of strategic technologies, including semiconductors, batteries, advanced mobility, nuclear power, biotechnology, aerospace, hydrogen, cybersecurity, AI, next-generation communications, robotics, and quantum. The government plans to invest approximately $22 billion over five years, with an emphasis on R&D, public-private partnerships, and commercialization.[189] Given the scope of these resources and the many technologies targeted, the plan includes partnering with like-minded partners such as the United States, Japan, and the European Union on research, legislation, and security.

Yet challenges loom. Studies indicate that the number of employment opportunities in STEM fields in South Korea is declining.[190] The country's declining and aging population presents serious long-term workforce sustainability issues.[191] The government has also been trending toward adopting EU-style legislation on digital trade and cybersecurity, which may dampen efforts to better integrate with U.S. companies.

South Korea's technology sector combines dominant global players with a considerable startup ecosystem.

INTEGRATION WITH THE UNITED STATES AND CHINA

The U.S.-ROK relationship runs deep through its military alliance, diplomatic engagement, and economic ties. South Korea is now one of the largest sources of foreign direct investment into the United States, funding projects in semiconductors and shipbuilding, initially due to incentives provided by the CHIPS and Science Act and the Inflation Reduction Act, and subsequently as a result of tariff negotiations with the Trump administration. South Korean companies are expected to invest tens of billions of dollars in the United States, including a $3.87 billion investment from SK Hynix to build an advanced semiconductor packaging facility and multiple billions into the U.S. shipbuilding industry from companies such as Hanhwa Ocean and HD Hyundai Heavy Industries.[192] The United States is the second-largest export destination for South Korea.

The ROK-China trade relationship also remains robust—China is the largest trading partner for South Korea.[193] It has made efforts to derisk economic entanglement with China to limit exposure to U.S. export controls and other punitive economic measures. SK Hynix and Samsung Electronics, two major U.S. investors, are heavily invested in Chinese facilities and export significant quantities of semiconductors to China. Export controls, including those on foundry manufacturing, have complicated South Korea's business and R&D efforts. Moving these profitable operations elsewhere is costly and would impact production quality and speed as companies build facilities and hire skilled workers.[194]

STRATEGIC VULNERABILITIES AND PROTECTION MEASURES

South Korea navigates economic pressure from both major powers. China, for example, has deployed coercive measures. Following the 2016-17 deployment of U.S. Terminal High Altitude Area Defense (THAAD) missile batteries to the Korean Peninsula, Beijing closed Korean businesses in China, issued travel advisories, stopped EV battery subsidies, and restricted imports.[195] Given the two countries' proximity and intertwined relationships, China can inflict significant pain on South Korea's supply chains and technology industries. The United States presents different challenges. Erratic tariff threats pose acute risks for South Korea's export-oriented economy, while semiconductor export controls complicate operations for SK Hynix and Samsung, whose facilities and customers remain heavily concentrated in China. South Korea must balance its security alliance with the United States against its economic relationship with China, its largest trading partner.

Besides geopolitical pressures, severe demographic decline presents a major endogenous risk to South Korean competitiveness. An aging and shrinking population reduces both tax revenue for government investment and the pipeline of skilled workers.[196] While automation and advanced technology will partially compensate, South Korea will require sustained partnerships with like-minded countries to maintain workforce capacity and technological competitiveness.

ILLUSTRATIVE CASE: SOVEREIGN AI STACK

South Korea is pursuing a sovereign AI stack.[197] It already possesses critical tools: semiconductors, AI models, researchers, and strong patent and publication records. The government has tasked its private sector with establishing a national AI model, selecting five business consortia to develop a fully domestic AI stack conditioned on South Korean data.[198]

Despite these ambitions, South Korea's AI stack remains deeply intertwined with the United States, creating a bidirectional relationship. Samsung's consortium continues using NVIDIA GPUs, and NVIDIA uses SK Hynix's high-bandwidth memory. SK Telecom's model trains on supercomputers using NVIDIA GPUs and AI data centers developed with Amazon.[199] SK Hynix intends to supply high-bandwidth memory to OpenAI for the Stargate project's global AI data centers.[200] South Korean companies have likewise invested billions in semiconductor facilities across multiple U.S. states.[201] This interdependence demonstrates how Stack technologies undercut sovereignty goals by enabling geographically dispersed competitive positions, which allows countries to leverage selective strengths across layers to compensate for dependencies in others.

India: Existing Engineering Depth, Growing Market Gravity

STRATEGIC ADVANTAGES

Understanding India's importance as a technology partner requires some amount of foresight. The India of 2050 will be an economic powerhouse with a GDP on par with the entire European Union and approaching that of the United States and China, presumably becoming one of the United States' top markets for technology exports.[202] This "economic gravity" will increase the odds that India integrates more deeply into technology supply chains—even if "by force" of Indian government policy. This integration can be accelerated with reduced investor pain if India aggressively pursues further economic reforms.

India is already a global technology leader in software development and engineering. Major Indian technology companies, including Tata Consultancy Services, Wipro, Infosys, and HCL Technologies, have deepened partnerships with the United States, evolving from basic tasks to complex commercial technology products jointly developed and manufactured in India. Texas Instruments pioneered this model, establishing a software design center in Bangalore in 1985, with many companies following.[203] However, India's success remains largely in design and engineering rather than novel technology development. India spends only 0.65 percent of GDP on R&D—about one-fourth of China's level and behind competitors like Thailand and Brazil.[204]

The India of 2050 will be an economic powerhouse with a GDP on par with the entire European Union and approaching that of the United States and China.

India's business environment has been improving but remains weaker than peer competitors in critical areas. Labor regulations impose strong government oversight for companies with more than 300 workers.[205] India ranks behind Brazil, Indonesia, Malaysia, Mexico, and Vietnam for political stability.[206] Nearly 40 sectors maintain foreign investment limitations, and the country's applied tariff levels, at 4.6 percent, exceed Thailand (3.7 percent), Malaysia (3.4 percent), Indonesia (1.8 percent), and Mexico (1.6 percent).[207] Yet India has become friendlier toward trade agreements, with recent robust agreements with Australia, the UAE, the United Kingdom, and the Swiss-led EFTA group, which has improved market access. India has also launched targeted technology missions: $9.2 billion for semiconductors, $1.2 billion for AI, and $720 million for quantum computing.[208] Digital governance tools, including India Stack for identity and payments and eCourts Mission Mode Project for legal system digitization, demonstrate capacity for rapid technological adoption.

INTEGRATION WITH THE UNITED STATES AND CHINA

India's economy is deeply integrated with the United States. Almost 20 percent of goods exports and 53 percent of software services exports route to the United States, and significant U.S. investment flows in the opposite direction.[209] At the same time, India relies heavily on technology imports from China. When including Hong Kong, China is India's largest goods trading partner, but the trade flows are heavily in China's favor. India has taken measures to reduce import reliance, including issuing quality control orders that require source-level assessments and expanding investment review mechanisms to include China.[210]

Yet India recently has shown greater receptivity to expanded commercial ties with China. Providing low-cost services to its population requires inexpensive Chinese materials like battery storage systems, and its manufacturing ambitions require inputs that can be sourced only from China, including rare earth batteries. Despite this thaw in the relationship, lingering border tensions create a ceiling on cooperation.

STRATEGIC VULNERABILITIES AND PROTECTION MEASURES

India's mixture of tariff and non-tariff trade barriers, paired with increasing mandatory local manufacturing mandates, is incentivizing more companies to invest in India to maintain market access.[211] As India's economic clout increases, such directives become more difficult for foreign companies to delay or avoid. This "forced localization" policy will drive integration even absent optimal business conditions. However, successive governments have tended to use policymaking levers to improve the business environment over 30 years, suggesting structural impediments will become less deleterious over time. U.S. policymakers will need to consider India's trajectory toward economic hyperpower status by mid-century when developing policies that shape integration with key partners, including export control tools. India's integration into U.S. technology supply chains will become increasingly significant, requiring India to prioritize strategic decisions about which partners receive preferential treatment for technology transfer and collaboration.

ILLUSTRATIVE CASE: AEROSPACE AND JET ENGINE CO-DEVELOPMENT

India, like many nations, seeks increasing self-reliance on domestically produced defense equipment—both to reduce dependence on other countries' strategic priorities and to fuel domestic job creation through the massive defense acquisition budget. This ambition intersects directly with one of the most challenging Precision technologies: jet engines.

In the 1980s, India launched a program to develop an indigenous light fighter, the Tejas, which continues to this day and requires foreign jet engine technology to maximize its combat capabilities. As part of the collaboration, Indian firm Hindustan Aeronautics Limited (HAL) will produce an engine developed by the United States' GE—the F414.[212] With a potential order book of hundreds of fighters, India pressed the U.S. Department of Defense and GE toward co-development and co-production of jet engines for the Tejas Mark 2 variant.[213]

This GE-HAL collaboration appears close to finalization—a remarkable development given that jet engine technology represents one of the most jealously guarded Precision technologies, with decades-long development cycles, tight-knit firm collaborations, and certification moats.[214] India's mixture of purchasing power and engineering sophistication, paired with the desire of successive U.S. administrations to deepen military cooperation, is enabling India to jump-start domestic jet engine development—a capability possessed by only a handful of nations. This case illustrates both India's leverage through market scale and America's willingness to share Precision technologies with partners it views as critical to long-term strategic competition. It also demonstrates how India can use mandatory localization policies and defense procurement to force technology transfer in ways that allies like the European Union or South Korea cannot.

ALLIED ECOSYSTEMS: LEVERAGE THROUGH INTERDEPENDENCE

Technology leadership depends less on bilateral superiority than on orchestrating allied ecosystems—no country commands absolute advantage, and deeply interdependent value chains can give partners outsized leverage. Europe provides Production and Precision technology excellence neither the United States nor China can replicate: high-end machine tools and aerospace systems built through generational expertise. South Korea dominates high-bandwidth memory essential for AI. India demonstrates how countries can surprise to the upside—leveraging market scale and localization policies to force technology transfer in Precision technology domains like jet engines that few nations master. Yet all three navigate competing pressures from Washington and Beijing while pursuing tech sovereignty agendas that risk fragmenting shared networks. For the United States, decisive advantage lies in orchestrating complementary strengths into integrated ecosystems that no centralized competitor can match—but this only works if allied cohesion holds. As it revitalizes technology alliances with these established trading partners, the United States can seize opportunities with new technology partners as well, such as Saudi Arabia and the UAE.

Appendix A

Methodology and Future Research

Standardized Index: Building Blocks (Chapter 4)

To enable cross-country comparison on heterogeneous indicators, we first collected all available country observations for each variable and included only indicators with coverage of at least 75 countries. To maximize the country count, we included all available countries per indicator for the most recent and comprehensive year, so the population of countries varied slightly for each indicator. For each indicator, we applied a 2nd-98th percentile trim to reduce the influence of extreme outliers while preserving the underlying distribution (nevertheless, results were robust without trimming). We then standardized each indicator by calculating country-specific z-scores relative to the global mean and standard deviation in that year, with indicator directionality adjusted so that higher values consistently reflect more favorable outcomes. To improve interpretability, these z-scores were linearly rescaled to a 50-centered index with a standard deviation of 20 (Index = 50 + 20×z), such that 50 represents the global average and each 20 points corresponds to one global standard deviation. Finally, the overall synthetic index for each country was computed as the unweighted average of its rescaled indicator scores across all included variables.

Qualitative Scorecard: U.S.-China (Chapter 4)

Industry Assessments, Unit of Analysis, and Time Frame

- **Industries assessed:** (1) AI stack, (2) commercial jet engines, (3) high-end machine tools (5-axis/ultra-precision focus), (4) rare earths (mining ➔ separation ➔ metals/alloys ➔ magnets)

- **Countries:** United States and China (other countries referenced qualitatively only to calibrate tiers)
- **Unit of analysis:** National capability at the industry level, with emphasis on frontier/high-end segments (i.e., the tiers that most strongly determine global technological leadership)
- **Time frame for status scores:** Current state as of the most recent 1–2 years of evidence available
- **Time frame for trend arrows:** Trajectory over the last 5–10 years (e.g., 2015–2025), based on directionality across the underlying indicators

Building Blocks Categories

- **Technology-Specific Enablers:** The tangible and human "inputs" that make frontier performance possible—R&D, talent/education, critical infrastructure and labs, IP/standards activity, and procurement that rewards innovation
- **Ecosystem Governance:** The way the industrial system learns, coordinates, and adapts—startup vibrancy and finance, regulatory clarity and speed, crisis adaptability, commercialization channels, and resilience
- **Enterprise Strategy:** The pattern of cooperation and competition among firms—depth of supplier/user co-development, presence of orchestrators, speed into emerging tech, embedded learning via service/aftermarket networks, and global value chains

Rubric Terminology

- **Dominant – Strong lead:** Globally competitive on inputs and outcomes with durable drivers; few weaknesses or vulnerabilities
- **Advanced – Advantages with gaps:** Strong inputs and outcomes, some constraints
- **Competitive – Mixed/contested:** Pockets of leadership upon which future improvements can be built, alongside clear and enduring weaknesses
- **Emerging – Disadvantage with some assets:** Clear weaknesses but leverageable assets exist
- **Lagging – Structural deficiencies:** Persistent shortfalls; thin capabilities and significant vulnerabilities

Industry Indicators

We used a basket of qualitative and quantitative indicators tailored to each industry:

- **AI stack (drivers):** Installed AI accelerator compute and AI-ready power (MW), model training runs at frontier scale, AI talent (graduate output, top-venue papers to), private capital expenditure (hyperscalers + startups), public AI R&D programs, participation in safety/standards fora, and orchestrator ecosystems (lab-cloud-app linkages)
- **Commercial jet engines (drivers):** Certification/test infrastructure depth, materials/process IP and supply chain for hot-section parts, FAA/EASA certification experience, MRO

network scale and power-by-the-hour/partnership models, installed base (for learning loops), and national S&T infrastructure (wind tunnels, combustor/icing rigs)

- **High-end machine tools (drivers):** Leadership in CNC controls/servo/encoder/metrology modules, precision component suppliers, 5-axis install density in advanced sectors, skilled trades/apprenticeship pipelines, OEM-module-user co-development, and cluster institutions (applied research institutes, standards)
- **Rare earths (drivers):** Capacity and yields in extraction ➔ solvent-extraction separation ➔ metals/alloys ➔ magnets, process know-how and impurity control, capital formation, industrial consolidation/quotas, export policy, stockpiles/off-take contracting, and university/lab/research specialization

Evidence types: Evidence was drawn from official statistics (e.g., certification/type-certificate lists, trade/production shares), major industry reports and associations, academic indexes (AI compute, publications), and credible think-tank datasets. We also used a variety of outcome data (market share at the high end, certified installed base, benchmark performance, etc.).

Other Factors

- **Adjudicating borderline cases:** When an industry × building block sat on the boundary (e.g., 3/4), we asked: "Does the preponderance of drivers (not outcomes) argue for advantage or for contestation with its competitors?" We also may have used this when determining arrow directionality, by tilting up or down by one to reflect momentum (e.g., US AI firm-strategy 4🡅 rather than "4➔").
- **Assigning trend arrows:** We based arrows on the directionality of indicators over 5-10 years:
    - If most driver indicators improved meaningfully: 🡅
    - If most were stable: ➔
    - If material deterioration appeared in multiple indicators: 🡇
    - When mixed, we weighted more forward-looking, funded drivers like long-term investments for long-cycle technology.
- **Treatment of tiers and sub-industries:** Where industries have quality tiers (e.g. 5-axis/ultra-precision vs. general machining), we weighted high-end tiers more heavily because they shape global leadership and spillovers.

Brief Summary of Scoring

AI Stack (United States)

- **Enablers: Dominant** ↑ Frontier compute, model labs, capital and talent still clearly ahead, and expanding
- **Governance: Advanced** → Strong startup ecosystem and standards/safety work, but regulatory and antitrust uncertainty keeps this from being "Dominant"
- **Firm Strategy: Advanced** ↑ Big orchestrators (OpenAI/Microsoft, Google, Meta, Anthropic, etc.) plus dense partner networks; multiyear AI capital expenditure pushes this slightly up

AI Stack (China)

- **Enablers: Competitive** ↑ Strong STEM talent, large internet platforms, and rising domestic accelerators; but constrained access to top Nvidia GPUs without clear, long-term domestic pathway to overcome compute handicap
- **Governance: Competitive** → Powerful state direction, rapid rule-making for generative AI and AI diffusion, but tight content controls and fragmented local implementation create both strengths (coordination) and frictions (uncertainty, chilling effects); trust gap on safety when internationalizing
- **Firm Strategy: Advanced** ↑ Large private sector orchestrators (Baidu, Alibaba/Qwen, Tencent, ByteDance, Huawei, etc.) with integrated data, apps, and cloud; fast productization in consumer and enterprise markets

Commercial Jet Engines (United States)

- **Enablers: Advanced** → GE/CFM and Pratt & Whitney remain two of the three global primes for large civil engines; strong test facilities and FAA certification expertise, but Europe (Rolls-Royce, Safran) is fully competitive, so this is "advantage with gaps", not undisputed lead
- **Governance: Competitive** → FAA processes underpin global safety but have faced scrutiny (7Competitive7 MAX, certification backlogs); coordination of industrial base, workforce, and climate constraints is mixed
- **Firm Strategy: Advanced** ↓ GE/CFM and P&W have deep airline relationships and global MRO networks, but margins are under pressure, big programs have cost overruns, and financial stress at OEMs/airframers slightly weakens their long-run innovation trajectory

Commercial Jet Engines (China)

- **Enablers: Lagging** ↑ AECC, COMAC programs and new test facilities; however, significant capability gaps, starting from material sciences and through precision manufacturing, including machine tooling; no engines are certified even in China, let alone FAA/EASA-certified large civil engines

- **Governance: Emerging ↑** Long-horizon state backing and clear strategic priority, but limited interaction with Western regulators and airlines; feedback loops are mostly internal to Chinese firms
- **Firm Strategy: Lagging ↑** AECC is state-owned, so major gaps in innovation and international trust; no commercial installed base on international routes, limited domestic airline willingness to rely on indigenous engines, and no global MRO network yet; trajectory is upward, but from a low and late starting point.

High-End Machine Tools (United States)

- **Enablers: Competitive →** Strong universities and some niche builders (aerospace R&D give "pockets of leadership," but no broad high-end machine tools ecosystem like Japan or Germany
- **Governance: Emerging →** Fragmented regional clusters, limited national MT policy, and thinner public test/tech centers and vocational training than in Germany and Japan
- **Firm Strategy: Emerging ↓** Many builders focus on mid-range; weaker long-term OEM-user networks and more episodic investment by user industries

High-End Machine Tools (China)

- **Enablers: Competitive ↑** Massive engineering pipeline, heavy industrial policy, and improving domestic CNC and components; still reliant on imported high-end controls/ precision parts but moving up the ladder
- **Governance: Emerging ↑** Strong national goals but uneven local execution because small and difficult market, SOE/private frictions, and price-driven tendering that undermines quality upgrading
- **Firm Strategy: Emerging →** Many fragmented players, thin margins, and relatively shallow long-term OEM-user ties in the top tier; a few champions emerging but not yet enough to shift the overall pattern

Rare Earth Elements (United States)

- **Enablers: Emerging ↑** New capital expenditure and R&D in mining, separation, and magnets due to government support and commercial urgency, but still a very small base compared to China
- **Governance: Competitive ↑** DOD/DOE programs, stockpiling, allied supply-chain deals, equity stakes and price-support mechanisms make the system more resilient than a decade ago
- **Firm Strategy: Emerging →** A few key firms (e.g., MP Materials, nascent magnet players) but fragile business economics and lack of scale mean this hasn't fundamentally shifted yet; with consistent government support, military usage could be fulfilled, but does not solve commercial insecurity (e.g., autos)

Rare Earth Elements (China)

- **Enablers: Dominant ➔** Comprehensive strength from mining through separation, metals and magnets, backed by specialized universities and institutes, with high skill development from researchers to vocational training
- **Governance: Dominant ➔** Consolidation into large groups, production, and export quotas, and some recent attention to environmental controls have reduced chaos and smuggling, though local interests and foreign diversification efforts are ongoing challenges; export controls, even on specialized equipment, will restrict diffusion
- **Firm Strategy: Advanced ➔** Large SOEs and national champions with global pricing power and long-term contracts, but less competitive pressure for efficiency/innovation than in a more diversified private ecosystem

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