The Great Tech Rivalry: China vs the U.S.

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The Great Tech Rivalry: China vs the U.S.
Executive Summary

To mark the arrival of the 21st century, in 1999 the National Academies of Science, Engineering, and Medicine offered an Olympian preview of the decades ahead. The Academy foresaw a world in which “yesterday’s science fiction [would] enter the marketplace: animal cloning, talking electronic road maps installed in automobiles, powerful computers as small as a pack of cigarettes.” Its Report declared that America’s “uniquely powerful system for creating new knowledge and putting it to work for everyone’s benefit” had been the primary engine of productivity growth in the 20th century and would likewise be the single largest determinant for the 21st century.¹

Rereading that report today, the elephant in the room it missed was China. In the future the Academy’s National Research Council envisioned, China hardly mattered. Reflecting the conventional wisdom of the era, Time Magazine’s special issue Beyond 2000 asserted confidently: “China cannot grow into an industrial giant in the 21st century. Its population is too large and its gross domestic product too small.”² With a per capita income at roughly the same level as Guyana and the Philippines, most Chinese did not have enough money to buy advanced technology products—let alone the resources to invent them.

By 2010, this picture was beginning to change. China had grown into a low-cost manufacturing site for multinational companies and was on its way to becoming the manufacturing workshop of the world for mass market goods. But according to the dominant school of thought at the time, as noted by China scholar William Kirby in the Harvard Business Review, many believed “China [was] largely a land of rule-bound rote learners” that could only imitate, not innovate.³ Advances in information technology could only be made in

free societies by free thinkers, not under an authoritarian regime behind a firewall, the logic went. So rampant were the issues of copycat software and shanzhai electronics in China that Microsoft famously abandoned its efforts to stem pirated copies of Windows.4

Today, China’s rapid rise to challenge U.S. dominance of technology’s commanding heights has captured America’s attention. The rivalry in technology is what the Director of the Central Intelligence Agency, Bill Burns, spotlights as the “main arena for competition and rivalry with China.”5 It has displaced the U.S. as the world’s top high-tech manufacturer, producing 250 million computers, 25 million automobiles, and 1.5 billion smartphones in 2020.6 Beyond becoming a manufacturing powerhouse, China has become a serious competitor in the foundational technologies of the 21st century: artificial intelligence (AI), 5G, quantum information science (QIS), semiconductors, biotechnology, and green energy.7 In some races, it has already become No. 1. In others, on current trajectories, it will overtake the U.S. within the next decade.

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President Xi Jinping has declared, “Technological innovation has become the main battleground of the global playing field, and competition for tech dominance will grow unprecedentedly fierce.”

Emphasizing the need to “develop indigenous capabilities, decrease dependence on foreign technology, and advance emerging technologies,” the Chinese government’s most recent Five-Year Plan identifies key performance indicators, sets deadlines for outcomes, and holds provincial and local governments accountable for delivering results.

One of America’s most respected leaders in advancing and applying technology, Eric Schmidt, who led Google to become one of the world’s leading technology companies, has been candid about his views. Noting that “many Americans still have an outdated vision of China,” he believes “the United States now faces an economic and military competitor in China that is aggressively trying to close our lead in emerging technologies.”

In his assessment: “Unless these trends change, in the 2030s we will be competing with a country that has a bigger economy, more research and development investments, better research, wider deployment of new technologies, and stronger computing infrastructure.”

To take stock of the state of the technology race, this report examines the progress made by the U.S. and China in each key technology over the past 20 years.

To begin with our bottom lines up front:

- In the advanced technology likely to have the greatest impact on economics and security in the decade ahead—AI—China is now a “full-spectrum peer competitor” in the words of Eric Schmidt.

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• In 5G, according to the Pentagon’s Defense Innovation Board, “China is on a track to repeat in 5G what happened with the United States in 4G.”¹² Despite advantages in 5G standards and chip design, America’s 5G infrastructure rollout is years behind China’s, giving China a first-mover advantage in developing the 5G era’s platforms.

• In quantum information science, America has long been viewed as the leader, but China’s national push presents a clear challenge. China has already surpassed the U.S. in quantum communication and has rapidly narrowed America’s lead in quantum computing.

• America retains its position of dominance in the semiconductor industry, which it has held for almost half a century. But China’s decades-long campaign to become a semiconductor powerhouse has made it a serious competitor that may soon catch up in two key arenas: semiconductor fabrication and chip design.

• The U.S. has seven of the ten most-valuable life sciences companies, but China is competing fiercely across the full biotech R&D spectrum. Chinese researchers have narrowed America’s lead in the CRISPR gene editing technique and surpassed it in CAR T-cell therapy.

• Though America has been the primary inventor of new green energy technologies over the past two decades, today China is the world’s leading manufacturer, user, and exporter of those technologies, cementing a monopoly over the green energy supply chain of the future. Consequently, America’s green push relies on deepening its dependence on China.

• China’s whole-of-society approach is challenging America’s traditional advantages in the macro-drivers of the technological competition, including its technology talent pipeline, R&D ecosystem, and national policies. As the National Security Council’s Senior Director for Technology and National Security Tarun Chhabra and the Center for Security and Emerging Technologies have recognized, “The United States is no longer the global science and technology (S&T) hegemon.”

As noted in the summary above, in the advanced technology likely to have the greatest impact on economics and security in the decade ahead—AI—Eric Schmidt, the former CEO of Google, states unambiguously: China is now a “full-spectrum peer competitor.” China’s AI surge is so recent that anyone not watching closely has likely missed it. Indeed, in many races, China has already overtaken the U.S. to become the world’s undisputed No. 1. Key indicators in the AI race include product market tests, financial market tests, research publications, patents, and results in international competitions.

Consumers’ choices of AI products in markets speak for themselves. In speech technology, Chinese firms are beating American firms in every language, including English. The world’s top voice recognition startup, China’s iFlytek, has 700 million users, almost twice the number of people who speak to Apple’s Siri.  

In financial technology (fintech), WeChat Pay’s 900 million Chinese users vastly outnumber Apple Pay’s 44 million in the U.S. While two-thirds of Americans still rely on credit cards, 90% of urban Chinese primarily use mobile payments, spending $150 on mobile platforms for every dollar Americans spend—in total, $42 trillion in 2020. This spending generates a treasure trove of granular data about individual consumer behavior that can be used to develop other fintech applications.

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13 Key sources consulted in the development of this section include: (i) Dr. Eric Schmidt, former CEO and Executive Chairman of Google, Chair of the National Security Commission on Artificial Intelligence, and the first Chairman of the Defense Innovation Board. (ii) Dr. Jason Matheny, the National Security Council’s Coordinator for Technology and National Security, Founding Director of the Center for Security and Emerging Technology, and former Director of IARPA. (iii) The National Security Commission on Artificial Intelligence, an independent commission established in 2018 to “consider the methods and means necessary to advance the development of artificial intelligence” for American national security. (iv) The Center for Security and Emerging Technology (CSET), a leading think tank focused on national security and emerging technologies, particularly artificial intelligence, advanced computing, and biotechnology. (v) Dr. Kai-Fu Lee, Chairman and CEO of Sinovation Ventures, former President of Google China, and author of AI Superpowers: China, Silicon Valley, And the New World Order and AI 2041: Ten Visions for Our Future. (vi) The Stanford AI Index, a comprehensive annual report on AI produced by the Stanford Institute for Human-Centered AI.


such as AI-driven assessments of individuals’ credit-worthiness. In facial recognition, there is no contest: the U.S. has essentially conceded the race because of concerns over individual privacy and deep reservations about how this technology could be deployed. Meanwhile, SenseTime and Megvii have developed cutting-edge applications like instantaneous facial recognition, which can identify individuals from China’s population of 1.4 billion in seconds.

Financial markets reflect these realities. Six years ago, two of the world’s twenty most valuable internet companies were Chinese; today, seven are. Google, Amazon, Facebook, Microsoft, Baidu, Alibaba, and Tencent—the “Seven Giants of the AI age”—are split on either side of the Pacific. Of every ten venture capital dollars invested in AI in 2018, five went to Chinese startups; four to American firms. Of the world’s top ten most valuable AI startups, seven are American and three are Chinese.

Chinese investments in AI research and development have surged to American levels, and the results are beginning to show. The reality is that China is laying the intellectual groundwork for a generational advantage in AI. The Air Force’s former Chief Software Officer, Nicolas Chaillan, even went so far as to claim that China’s victory in the AI race is “already a done deal.” Last year, China overtook the U.S. for overall AI citations, with a 35% increase from 2019. In AI’s hottest subfield—deep


learning—China has six times more patent publications than the United States. And according to the authoritative assessment of the Allen Institute for Artificial Intelligence, the United States will fall to second in the top 1% of most-cited AI papers by 2025.25

AI researchers are eager to demonstrate their progress and prowess in international competitions. For example, in 2017 DeepMind’s AlphaGo Master defeated the Go world’s grand master, Ke Jie, a decade sooner than experts had predicted. Eight months later, Tencent’s own Go program, called “Fine Art,” also beat Ke (and Fine Art won despite giving Ke a two-turn head start—a handicap DeepMind had been unwilling to offer).26 At Stanford’s international challenge for machine reading comprehension, Chinese teams regularly dominate the top five spots, including first place.27 And in the world’s most prestigious computer science competition for secondary school students, the International Olympiad in Informatics, Chinese have won 88 gold medals while Americans have won 55.28

In the longer-term competition, China’s advantages begin with its population of 1.4 billion that creates an unparalleled pool of talent and data, the largest domestic market in the world, and universities that are graduating computer scientists in multiples of their American counterparts. China graduates four times as many bachelor’s students with STEM degrees and is on track to graduate twice as many STEM PhDs by 2025.29 By contrast, the number of domestic-born AI PhDs in the U.S. has not increased since 1990.30

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26 Go is the world’s most complex board game. Even after several American companies’ machines had bested the world’s chess masters, most Chinese remained confident that machines could never beat Go champions, since Go is approximately ten thousand times more complex than chess as measured by the total number of possible moves. In March 2016, AlphaGo, an AI system designed by DeepMind, beat Lee Sedol, one of the world’s best Go players in a best-of-five series, winning four out of five games; and at the 2017 Future of Go Summit, AlphaGo’s Master version beat world champion Ke Jie in a three-game match. See Cadie Metz, “Google’s AI Wins Fifth and Final Game Against Go Genius Lee Sedol,” Wired, March 15, 2016, https://www.wired.com/2016/03/googles-ai-wins-fifth-final-game-go-genius-lee-sedol/; Tom Simonite, “Tencent Software Beats Go Champ, Showing China’s AI Gains,” Wired, January 23, 2018, https://www.wired.com/story/tencent-software-beats-go-champ-showing-chinas-ai-gains/.


Because a primary asset in applying AI is the quantity of quality data, China has emerged as the Saudi Arabia of the twenty-first century’s most valuable commodity. Even so, the United States enjoys two advantages in human capital that Beijing cannot replicate. First, half of the world’s AI superstars work for U.S. companies. Second, America can recruit from all the world’s 7.9 billion people, while inherent insularity restricts China to its own population.

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32 Besides these advantages in human capital, the United States also has the potential to leverage its alliances and security partnerships to ensure liberal democratic values are embedded in the development of AI systems. Tarun Chhabra and his colleagues at the Center for Security and Emerging Technologies recommend a “three-pronged strategy: (a) defend against the threats posed by digital authoritarianism, (b) network with like-minded countries to pool resources and accelerate technological progress, and (c) project influence and leverage safe and reliable AI in support of inclusive growth, human rights, and liberal democratic values.” See Andrew Imbrie, Ryan Fedasiuk, Catherine Aiken, Tarun Chhabra, and Husanjot Chahal, “Agile Alliances: How the United States and Its Allies Can Deliver a Democratic Way of AI,” Center for Security and Emerging Technologies, February 2020, https://cset.georgetown.edu/publication/agile-alliances/; Jason Matheny, Arina Roy, Takatoshi Miura, Tobias Feakin, Gilman Louie, and Dhruva Jaishankar, “Quad Cooperation on Artificial Intelligence,” Observer Research Foundation America, June 10, 2021, https://orfamerica.org/recent-events/quad-cooperation-on-artificial-intelligence.


To the extent that the next decade is an era of implementation, the advantage lies with China. As the National Security Commission on Artificial Intelligence assessed, “China possesses the might, talent, and ambition to surpass the United States as the world’s leader in AI in the next decade if current trends do not change.” However, if the most significant advances in AI in the next decade come from breakthrough leaps in algorithms and hardware, the advantage lies with the U.S.

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5G

In telecommunications—the infrastructure that serves as the backbone of mobile communications—the Defense Innovation Board gives a succinct summary of the state of play: “China is on track to repeat in 5G what happened with the United States in 4G.” If it succeeds, China will have a first-mover advantage in a technology with significant commercial, intelligence, and military applications.

With increases of up to a hundredfold in speed, fiftyfold in reliability, and tenfold in device connections, 5G promises to enable new use cases no one can even imagine today. Qualcomm’s Economic Strategy Team estimates that over the next 15 years, 5G will “add an economy the size of India” to the world, the lion’s share of which is on track to be in China. Industry association GSMA states that China “now represents the single largest 5G market in the world, with 5G connections in the country accounting for 87% of global 5G connections at the end of 2020.”

Indeed, nearly all key indicators support projections that China will dominate the 5G future. By the end of 2020, China had 150 million 5G users to America’s 6 million; 700,000 5G base stations to America’s 50,000; 460 MHz of licensed mid-band spectrum to America’s 70 MHz; and 300 Mbps in

36 Key sources consulted in the development of this section include: (i) The Defense Innovation Board, an independent advisory board for the Secretary of Defense founded to bring technological innovation and industry best practices to the Defense Department. (ii) Qualcomm, a leading U.S. company that specializes in chip design, software, and wireless technology services. (iii) GSMA, an industry organization that represents the interests of mobile operators worldwide, uniting more than 750 operators with almost 400 companies in the broader mobile ecosystem.


41 Eric Schmidt assesses that “China is ten times ahead of us in the 5G space...We may have already lost [the infrastructure rollout race].” See “GPS Web Extra: Eric Schmidt on the Race to 5G,” CNN GPS, March 7, 2021, https://www.cnn.com/videos/tv/2021/03/07/exp-gps-0307-web-extra-schmidt-on-5g.cnn.
average 5G speeds to America’s 60 Mbps. Of the five major 5G equipment providers, two are Chinese; zero are American. Over the past two decades, China’s national champion Huawei has gone from 0% market share in telecommunications infrastructure to becoming the world’s leading supplier of 5G equipment, with 28% market share (while former American national champions Lucent and Motorola crashed from 25% in 2000 to 0% today). Despite the Trump Administration’s effort to, as a former NSC staffer described it, “kill Huawei,” the tech giant still deployed more than 300,000 5G base stations in China last year. Huawei has lost market share in mobile phones, but it successfully spun off its subsidiary, Honor, which has subsumed Huawei’s domestic market share, growing to become a top-five smartphone maker in China, while dodging U.S. sanctions. And, as singled out by President Xi Jinping last year, 5G infrastructure is a top priority in the $1.4 trillion New Infrastructure Plan for upgrading China’s post-COVID economy. In short, China has all the ingredients for nationwide 5G networks that will enable AI and the Internet of Things to reach further into everyday


life, as seen this past May when Baidu rolled out China’s first driverless robotaxis powered by Beijing’s 5G networks.46

The U.S. maintains a competitive edge in other segments of the 5G race, notably in 5G R&D, standards, and applications. American 4G patents underpin the fundamental building blocks of 5G, and U.S. companies currently chair a plurality of committees at the industry standards body 3GPP.47

Recognizing the value of 5G standards and fueled by high R&D budgets, Chinese companies are aggressively expanding their influence at standards bodies—and eroding America’s. Huawei leads in shares of 5G patent families granted by the U.S. and European patent offices and in approved 5G technical contributions to 3GPP, while China has already set its sights on the next generation of mobile communications and holds 35% of 6G patents compared to America’s 18%.48

In 5G applications, America’s advantages include its tech giants’ centrality to the global tech ecosystem, leadership in 5G chip design, and dominance of key related technologies such as cloud infrastructure. But the brute fact is that without robust national 5G infrastructure and users living in 5G environments, the U.S. will be at a disadvantage in developing the next killer applications for 5G. Widespread 5G networks with real 5G capabilities are still one to two years away in the U.S., while mainstream adoption of new infrastructure solutions like ORAN (which some have proposed as America’s

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answer to Huawei) will come too late for the U.S. 5G rollout. 49 In contrast, as Schmidt warns, “China will soon have a national network with speeds of 1 gigabit a second. With China’s head start, the next generation of technology giants—and the products and services they build—are not going to be European or American but Chinese.” 50

China is already pioneering cutting-edge 5G applications, including smart factory systems, digital twins for industrial applications, and the world’s first 5G-enabled remote surgery. 51 Where the 4G era saw Apple iPhones, Google Android OS, and Microsoft HoloLens connecting users to the tech ecosystem, 5G is poised to be dominated by Huawei networks offering ubiquitous connectivity for Xiaomi smartphones, Tencent smart city solutions, and Baidu robotaxis.

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Quantum Information Science

In quantum computing, quantum communication, and quantum sensing—three consequential subfields within quantum information science (QIS) traditionally led by American researchers—China is catching up and, in some cases, has already overtaken America. Pioneered 30 years ago, QIS is a field long seen in the scientific community as a potential catalyst for revolutionary advances in science and technology involving large computations, much faster communication, and precision measurement. Governments have only recently recognized that national security threats once considered hypothetical are becoming possible. Indeed, threats like the ability to crack existing encryption to steal state secrets, the creation of fully secure lines of communication, and sensors so precise that they could liberate operational platforms from their reliance on space-based positioning systems may not be as far off as previously thought.

Unlike prior technological revolutions that took place when China was still a poor country, China’s meteoric rise has provided it with the funds and manpower to potentially lead this field. Pan Jianwei, dubbed...
China’s “father of quantum,” said it best: “We were only the follower and the learner at the birth of modern information science. Now we have a chance…to be a leader.”55 In 2014, the U.S. and China were tied in the number of quantum-related patents, and in 2015 China was second only to America in annual spending on quantum technology research.56 But by 2018—two years after China launched a “megaproject” aiming to make breakthroughs in QIS by 2030—China passed the U.S., filing more than twice as many patents and accounting for 52% of all quantum patents.57 Today, China is spending four times more than the U.S. on QIS. 58 As a result of these advances, a 2017 report by the U.S.-China Economic and Security Review Commission declared that “China has closed the technological gap with the United States in quantum information science—a sector the United States has long dominated.”59 Since that assessment, Beijing has doubled down, naming QIS a top tech priority second only to AI in its 14th Five Year Plan.60

Quantum Patents Per Year

Sources: “Quantum Technologies Patents, Publications & Investments,” Le Lab Quantique

58 Signed in 2018, the National Quantum Initiative Act has committed America to spend $1.2 billion for QIS over five years. In February 2020, additional funding of $860 million was promised, as well as another $492 million in 2021. In China, funding for QIS is estimated at $10 billion, which has allowed leading institutions like the National Laboratory for Quantum Information Science and the Beijing Academy of Quantum Information Sciences to develop some of the world’s top quantum research facilities. See Michel Kurek, “Quantum Technologies Patents, Publications & Investments.”
The United States had long been a leader in quantum computing thanks to heavy investments from private companies, including Google, IBM, Intel, and Microsoft, who have helped America be the first to achieve the most important milestones in the field to date, including demonstrating “quantum supremacy” and rolling out cloud computing services allowing clients to use quantum computers.61 China is eager to catch up to the U.S., elevating quantum computing to the status of a “strategic technology” in 2017 to allow for increased investment. As a result, a Chinese institution, Harbin Engineering, has already secured a spot in the top five for number of patents related to quantum computing software (while U.S. companies hold the top three spots and dominate in patents for hardware).62

China has also demonstrated the ability to rapidly turn R&D into operational supremacy. In December 2020, only one year after Google’s 53-qubit Sycamore superconducting quantum computer achieved quantum supremacy,63 China reached the same milestone. That month, a photonic quantum computer created by the University of Science and Technology of China reached quantum supremacy “10 billion times faster” than Google.

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63 Quantum supremacy, also known as quantum advantage, is an achievement that refers to when a quantum system can solve a problem deemed impossible for a classical computer to solve in a reasonable amount of time. Quantum bits, or “qubits,” are the quantum version of today’s computer bits. Each additional qubit could grow a quantum computer’s power exponentially.
for certain calculations in physics. And only six months later, a team led by Pan Jianwei again made headlines with a new quantum processor, Zuchongzhi, which usurped Google’s Sycamore as the world’s most powerful superconducting quantum computer by solving a problem 100 times more challenging than the one solved by Sycamore, as measured by the types of mathematical analysis required to perform the computation. In photonic qubits, which have the potential for faster operation and are essential for its emerging quantum network, China is ahead with 113 detected photons. However, in terms of quantum volume, a metric invented by IBM that evaluates not only the quantity of qubits but also their connectivity and quality, the U.S. leads with Honeywell claiming a quantum volume of 1024.

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A general-purpose quantum computer is likely still decades away, with the challenge of scaling holding the field back. 68 Nevertheless, until a general-purpose quantum computer exists, less powerful quantum computers can significantly shorten the time it takes classical computers to solve certain problems. In one such case, Google recently simulated a chemical reaction using only 12 of its Sycamore quantum computer’s 53 qubits, a step forward in quantum chemistry. 69

Four years ago, the U.S.-China Economic and Security Review Commission reported that “China has now surpassed the United States to become the world leader in quantum communication.” 70 In this subfield, China did not start from a position of weakness. Although the U.S. developed the first quantum key distribution network in 2003, it has since lost its edge in the quantum communication race. 71

### Quantum Publications (2010 - 2020)

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*Total Publication (TP), Total Citation (TC), Citation Per Publication (CPP)


information gathering capabilities in China galvanized Beijing to accelerate progress in quantum communication—the “gold standard” for security. As a result, in 2018 China registered over four times more patents than the U.S. in quantum communication and cryptography (517 to 117). And since 2014, it has overtaken the U.S. and Europe (another leader in the field) in publications.

China’s milestones in quantum communication are impressive. In 2016, China launched Micius, the world’s first quantum communication-enabled satellite. Shortly afterward, Chinese scientists created a record-breaking quantum communication link between satellites and an earth station separated by more than 745 miles. And in January this year, China announced the creation of the world’s first integrated quantum communication network spanning a total distance of over 2,800 miles (longer than the distance from New York to Los Angeles). One expert expects Chinese government and military communications will go black in as little as two to three years, meaning the U.S. would no longer be able to listen in.

Compared to quantum computing and communication, quantum sensing is a relatively mature field where real-world capabilities are already emerging.
This is particularly important for military capabilities, where quantum sensing has the most direct applications, including the ability to nullify stealth technologies and radar jamming. According to a 2019 report by the Institute for Defense Analyses, of all the publications on quantum sensing, China ranked third in average citations per paper (the U.S. ranks first, Europe second). However, in publications from just the last five years, China ranked first in citations per paper and total publications on quantum sensing.

In a 2017 congressional hearing, one prominent expert on the U.S.-China rivalry in quantum information science summarized America’s relative decline succinctly: “The U.S. was once the leader…but the lack of funding, structural and institutional issues, and lack of government coordination have reduced both the levels and consistency of support that are necessary to maintain capacity in this critical research area.” Recent initiatives and increased funding have attempted to rectify some of these shortcomings, but more is needed to compete. Much like other advanced technologies, since America does not have a monopoly on quantum expertise, it must work with strategic allies and partners like Japan who have more advanced technology in quantum communication and encryption. As Jason Matheny, the National Security Council’s Coordinator for Technology and National Security, warns: “our advantage [in quantum technologies] is fragile.”

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80 Stuart A. Wolf et al., Overview of the Status of Quantum Science and Technology and Recommendations for the DoD.


83 Akira Oikawa, Yuki Okoshi, and Yuki Misumi, “China Emerges as Quantum Tech Leader while Biden Vows to Catch Up.”

Semiconductors

As a core element to many everyday technologies, including AI, computers, automobiles, and more, semiconductors are an essential general-purpose driver in the U.S.-China tech competition. The U.S. retains its dominance of the semiconductor industry that it has had for almost half a century, but this position has been gradually eroded by domestic underinvestment and rising overseas competition. Although the U.S. still leads in chip design and semiconductor manufacturing inputs, its share of semiconductor fabrication has fallen from 37% in 1990 to 12% today. Meanwhile, China’s decades-long campaign to become a semiconductor powerhouse has yielded significant results in recent years. Although “the Mainland is not yet a competitor,” as assessed by Taiwan Semiconductor Manufacturing Company (TSMC) founder Morris Chang, China has narrowed its gap in semiconductor production and design to just one to two generations behind lead players. Over the next decade, China will become the world’s largest semiconductor producer in mature technology nodes, while ASML CEO Peter Wennink estimates that “in 15 years’ time they’ll be able to do it all by themselves [and achieve technological sovereignty in semiconductors].”

With a three-fold increase in its share of global semiconductor consumption (from less than 20% in 2000 to 60% in 2019), China’s growing domestic demand has provided both market and national security incentives to expand its push into the semiconductor industry, culminating in

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85 Key sources consulted in the development of this section include: (i) Dr. Morris Chang, founder and former Chairman/CEO of Taiwan Semiconductor Manufacturing Company (TSMC). (ii) The Semiconductor Industry Association (SIA), a trade association that represents the U.S. semiconductor industry. (iii) The National Security Commission on Artificial Intelligence.


two notable successes. First, in semiconductor fabrication, China’s share of global semiconductor manufacturing capacity has surpassed America’s at 15%, up from less than 1% in 1990, while the U.S. share has fallen from 37% to 12%. The Semiconductor Industry Association projects that over the next decade, China will develop 40% of new global capacity and become the world’s largest semiconductor manufacturer, with 24% market share. Moreover, China’s national champion in semiconductor fabrication, Semiconductor Manufacturing International Corporation (SMIC), has consistently ranked among the top five foundries over the past decade, and its breakthrough N+1 7-nanometer process last year means that its advanced fabrication capabilities now rival Intel’s. Second, in the chip design arena, Huawei’s HiSilicon subsidiary has grown into an integrated circuit design powerhouse. In 2020, it became the first Chinese company to break into the top ten semiconductor companies and replaced long-time market leader Qualcomm as China’s top smartphone processor supplier, though export controls have damaged the company’s near-term prospects. While China is still dependent on semiconductor imports to meet 85% of domestic demand, these recent achievements disprove the decades-long conventional wisdom that China’s semiconductor industry cannot catch up. Indeed, by Chang’s best judgement, China is only “one to two years behind the U.S. and Taiwan” in chip design and “five years behind TSMC” in fabrication.

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90 This competition between firms is measured by the technology node (or generation of semiconductor technology, with partial relation to scale). Although not yet commercialized, SMIC’s newly developed N+1 process is similar to TSMC’s 7nm process without requiring EUV lithography machines, while Intel’s current 10nm process is similar to TSMC’s 7nm. See Dave Makichuk, “China a Step Closer to Microchip Independence,” Asia Times, December 1, 2020, https://asiatimes.com/2020/12/china-a-step-closer-to-independence-in-microchip-war/; Richard Waters, “Intel’s Manufacturing Hold-up Sends Shockwaves Through Chip Industry,” Financial Times, July 24, 2020, https://www.ft.com/content/05b2b80-d53b-410e-8e80-f433d25a87d4.  
92 Chang’s estimates refer to how far behind China’s technology is, not how many years it would take China to catch up, but China has been continuously decreasing the gap between its technology and those of market leaders. ASML’s CEO estimates that China can catch up in 10-15 years. Major hurdles include access to talent and the need to develop indigenous semiconductor manufacturing inputs (such as electronic design automation software and semiconductor manufacturing equipment).
With 48% overall industry market share compared to China’s 5%, the U.S. is the undisputed global leader in semiconductors. Yet, its positions in the design and fabrication arenas have weakened significantly. American companies like Qualcomm and Nvidia dominate the list of top semiconductor companies with 7 out of 10 spots, but revenue rankings fail to reflect long-term vulnerabilities like R&D budgets constrained by debt, a growing shortage of semiconductor talent, and increasing reliance on Chinese companies as major revenue sources. And whereas the U.S. was formerly operating at the leading-edge of chip fabrication, only 44% of U.S.-designed chips are fabricated domestically today. Both Intel and GlobalFoundries are far behind in the next-generation chip competition, leaving 90% of advanced fabrication in the hands of Taiwan-based TSMC.

As stated by Intel CEO Pat Gelsinger, this means that “the most important building block for our economic livelihood and every aspect of human life is now increasingly not in our control.” In semiconductor manufacturing inputs, America retains a strong position and controls key supply chain choke points through firms like Applied Materials and Lam Research, holding 55% market share of semiconductor manufacturing equipment (versus 2% for China) and 85% of electronic design automation software.

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95 Although Intel is trying to re-enter the leading-edge fabrication competition and recently unveiled an ambitious five-year innovation roadmap, the U.S. is unlikely to catch up to TSMC in the next ten years. As assessed by industry experts, the most likely scenario is that TSMC maintains its lead in the most advanced chips, while the U.S. remains 1-2 generations behind TSMC and continues to produce a significant share of mature node chips. See Asa Fitch, “Intel Sets Plan to Again Become World’s Premier Chip Company,” Wall Street Journal, July 26, 2021, https://www.wsj.com/articles/intel-sets-plan-to-again-become-worlds-premier-chip-company-11627333200; Kathrin Hille, “TSMC: How a Taiwanese Chipmaker Became a Linchpin of the Global Economy,” Financial Times, March 23, 2021, https://www.ft.com/content/05206915-fd73-4a3a-92a5-6760ce965bd9; “2020 State of the U.S. Semiconductor Industry,” SIA, June 2020, https://www.semiconductors.org/2020-state-of-the-u-s-semiconductor-industry/.


Together, these trends suggest that while the U.S. will not be displaced as an industry leader in the near-term, China has made strong progress in two of three critical arenas that, if maintained, could see China's semiconductor industry grow rapidly within the next decade. Though recent U.S. actions like sanctions on Huawei and SMIC’s inclusion on the Entity List have slowed China's progress, completely cutting off China's access to advanced semiconductors would be a self-sabotaging policy, since the Chinese market accounts for 36% of all U.S. chip sales.\(^8\)

\(^8\) Since 2019, the Commerce Department has added over 300 Chinese companies including Huawei and SMIC to the Entity List, a trade blacklist which restricts access to national security-controlled goods and technologies. Most notably, the Entity List designation cut off Huawei's purchases of advanced semiconductors that were made using U.S.-sourced equipment and SMIC's access to U.S.-made semiconductor manufacturing equipment for leading-edge chips. Due to these restrictions, Chinese firms have been researching replacements to American technology and achieving self-sufficiency where possible. For example, Huawei's HiSilicon has developed its first chipset based on the open-source RISC-V architecture as an alternative to the more commonly used Arm architecture, which arguably falls under the Entity List restrictions. "China’s Accelerated Bid for Semiconductor Self-Sufficiency Will Have a Global Impact from 2021," Analysys Mason, May 6, 2021, https://www.analysysmason.com/research/content/comments/china-semiconductors-chips-rds0/; Jimmy Goodrich and Zhi Su, "The U.S. Should be Concerned with its Declining Share of Chip Manufacturing, Not the Tiny Fraction of U.S. Chips Made in China," SIA, July 10, 2020, https://www.semiconductors.org/the-largest-share-of-u-s-industry-fab-capacity-is-in-the-united-states-not-china-lets-keep-it-that-way/; Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, “Strengthening the Global Semiconductor Supply Chain in an Uncertain Era.”
As former Deputy Secretary of Defense Robert Work has recognized, “We’re 110 miles [the width of the Taiwan Strait] away from going from two generations ahead to maybe two generations behind.”

The undeniable reality is that China’s potential to become a semiconductor leader can no longer be discounted; and, on the current trajectory, it is more likely than not that President Xi will accomplish his goal of China becoming a top-tier player in the semiconductor industry by 2030.

99 This refers to China’s ability to target America’s asymmetric dependence on TSMC and other Taiwanese firms for powering both its semiconductor industry and broader digital ecosystem. See Demetri Sevastop, “China on track to surpass U.S. as ‘AI superpower’, Congress warned,” Financial Times, March 1, 2021, https://www.ft.com/content/37cf699a-1d5e-4dfe-be65-84682cb15532.

100 In the most likely scenario, by 2030, China will become the world’s largest producer of semiconductors (specifically in mature nodes); TSMC will maintain its lead in leading-edge fabrication, with Samsung close behind and the U.S. and China 1-2 generations behind; and the U.S. will remain the leading supplier of semiconductor manufacturing equipment and electronic design automation software. See James A. Lewis, “Learning the Superior Techniques of the Barbarians: China’s Pursuit of Semiconductor Independence,” Center for Strategic & International Studies, January 2019, https://ciswebsite-prod.c3.amazonaws.com/s3fs-public/publication/190115_Lewis_Semiconductor_v6.pdf.
Biotechnology is the development of new technologies derived from discoveries in the life sciences, encompassing diverse categories like genomics, biochemistry, molecular biology, and more. As described by neuroscientist and former MIT president Susan Hockfield, “A century ago, physics and engineering came together and transformed our world completely, and now biology and engineering are poised to transform our future as profoundly.”

Looking towards this future, the U.S. is the undisputed leader in biotech, but China is competing fiercely across the full biotech R&D spectrum, and in some instances even winning.

Over the past two decades, China has vaulted to the top ranks of biotech basic research. From 2007-2017, China’s biotech publications increased by 20% annually, with the second most publications after the U.S. In 2019 and 2020, China overtook Germany and the U.K. respectively and now ranks second in the Nature Index for high-quality life sciences research, increasing its annual output by 9% over the past year. Notably, its research output has exceeded America’s in multiple areas, including in CRISPR-modified crops (42% vs. 19% share) and transgenic plants (30% vs. 12% share). China also produces the most biotech patents annually, increasing its global share from 1% in 2000 to 28% in 2019 while the U.S. share dropped from 45% to 27%. In biomedical patents, China’s annual growth rate of 16% far exceeds America’s 3%, and in cell therapy patents China leads in both total patents and growth rate.

Where China lags in basic research, it has excelled in developing applications. Consider genomics and genomic technology as a representative arena. While the U.S. led the world in coordinating and completing the

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101 Key sources consulted in the development of this section include: (i) Nature and Science, two of the world’s leading scientific journals in all fields of science and technology. They also publish science-related news and analyze coming trends affecting science, science policy, and the wider public. (ii) The Information Technology and Innovation Foundation, one of the most authoritative think tanks focused on science and technology policy.


Human Genome Project at the start of the millennium, China in 2018 launched the world’s largest genome project, which project director Dr. Wang Yadong stated will “map out [the] Chinese people’s genome atlas by sequencing the genes of 100,000 individuals, in an effort to identify [the] genetic basis of health disorders of Chinese.”\textsuperscript{107} After acquiring U.S.-based Complete Genomics in 2013, Chinese genomics giant BGI is now the world’s largest genetics research center and can sequence human genomes for a record-breaking $100 (6 times less expensive than its competitors and 100,000 times cheaper than the cost in 2000).\textsuperscript{108} In CRISPR research, the U.S. maintains a lead in total papers published, but this lead is much narrower for recent years. In 2018, the U.S. published 898 papers and China published 824.\textsuperscript{109} More notably, that same year, Chinese scientist He Jiankui crossed a bioethical red line when he used CRISPR to create the world’s first genetically-modified babies. Although He was later criticized for violating Chinese and international bioethical standards, this case was nonetheless reflective of China’s looser regulations around CRISPR applications, which have allowed China’s human studies to far outpace those in the United States, with half of all CRISPR clinical trials taking place in China.\textsuperscript{110}

In biopharmaceuticals and therapeutics, China has proved itself to be a rising competitor in turning lab discoveries into commercial products. Since 2001—and particularly after recent policy shifts such as the 2015 reform of the China Food and Drug Administration—China has increased its share of the global biopharmaceutical market from 7% to 22% (the second largest globally after the U.S.); become the world’s largest producer of active pharmaceutical ingredients and other key inputs (accounting for 40% of global output); and expanded its biopharmaceutical production


\textsuperscript{108} Although genome sequencing is not an innovative technology itself, China’s ability to do so cheaply and at-scale reflects its strengths in process innovation, which provides advantages such as cheaper access to genetic data. See Antonio Regalado, “China’s BGI Says It Can Sequence a Genome for Just $100,” MIT Technology Review, February 26, 2020, https://www.technologyreview.com/2020/02/26/905658/china-bgi-100-dollar-genome/.

\textsuperscript{109} CRISPR is a versatile gene-editing technology that enables scientists to modify DNA sequences quickly and accurately. CRISPR’s applications include treating diseases, modifying crops, and controlling insect vectors that spread disease, but the technology can also contribute to security threats such as engineered bioweapons. While American CRISPR papers are more widely cited than Chinese papers, both the U.S. and China are far ahead of other countries in CRISPR—Japan is a distant third with one-fourth as many publications as China. China’s looser regulations around CRISPR clinical trials yield advantages for it in developing new CRISPR applications. See “Final Report of the Emerging Technologies Subcommittee: Biotechnology,” Homeland Security Advisory Council, August 18, 2020, https://www.dhs.gov/sites/default/files/publications/final_hsic_emerging_technologies_biotecnology_report_8_18_2020_-_508.pdf; Jon Cohen and Nirja Desai, “With its CRISPR Revolution, China Becomes a World Leader in Genome Editing,” Science, August 2, 2019, https://www.sciencemag.org/news/2019/08/its-crispr-revolution-china-becomes-world-leader-genome-editing.

to 15% of global capacity with a 10% annual growth rate (ranked third in
global capacity after America’s 35% and the E.U.’s 25%). Though much of
China’s biopharmaceutical growth has been driven by generic drugs, bio-
similars, and a large domestic consumer base, China’s innovative capacity
has also been growing: over the past decade, it has tripled the number of
“innovative molecules” in development to 800, with 10% in clinical stage
III and 25% undergoing trials overseas. Despite being significantly less
effective than the innovative mRNA vaccines developed by American
firms, the coronavirus vaccines developed by Sinopharm and Sinovac are
nonetheless impressive achievements that have both been approved by the
World Health Organization for emergency use and, out of all vaccines,
have been used to vaccinate the most people globally. Still, the clear prefer-
ence of the international community is for American vaccines.

The most prominent testament to China’s biotech success is CAR T-cell
(CAR-T) therapy, which modifies T cells for use in immunotherapy and
has shown promise in cancer treatment. In the race to dominate the
CAR-T market, Nanjing Legend Biotech emerged in 2017 as the clear frontrunner when it presented some of the best breakthrough data in
decades in oncology: 94% of patients with multiple myeloma had clinical
remission after Legend’s CAR-T treatment. Within months, Johnson &
Johnson (J&J) entered into a licensing agreement to access Legend’s

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111 Recent policy shifts such as the 2015 reform of the China Food and Drug Administration and its 2018 restructuring
into the National Medical Products Administration (a ministerial-level agency) have accelerated the drug approval
process and the timelines of clinical trials. See Cathy Yarbrough, “China’s Latest Approach to Drug Development
articles/2021/mar21/elearning-mar21; Robert D. Atkinson, “China’s Biopharmaceutical Strategy: Challenge or
Complement to U.S. Industry Competitiveness?” Information Technology & Innovation Foundation, August 12,
top1000bio.com/.
113 Sinopharm’s vaccine (BBIBP-CorV) and Sinovac’s vaccine (CoronaVac) have been approved by the World Health
Organization for Emergency Use Listing. The coronavirus vaccines developed by Sinopharm and Sinovac have
been approved in 72 and 47 countries respectively (compared to 85 for J&J). China has exported more vaccines
than all other countries combined and is on track to produce over 3 billion doses this year. See “WHO Validates
Organization, June 1, 2021, https://www.who.int/news/item/01-06-2021-who-validates-sinovac-covid-19-vaccine-
trackvaccines.org/vaccines/; Zeke Miller, “Biden doubles US global donation of COVID-19 vaccine shots,” AP,
united-nations-e7c09c189c4b56c06505d278bd3.
114 David Crow, Tom Hancock, and Wang Xueqiao, “Healthcare: Cancer breakthrough leads China’s biotech boom,”
Financial Times, April 10, 2018, https://www.ft.com/content/30b6a944-3b57-1eb-859f9-de94e33a89e. “Janssen
Enters Worldwide Collaboration and License Agreement with Chinese Company Legend Biotech to Develop
technology, which J&J’s head of cancer research praised as an “innovative approach with the potential to transform the treatment of myeloma.” Since then, China has become the world’s largest sponsor of CAR-T therapy clinical trials (with over 50% of trials by 2020) and is on-track to dominate this novel technology, which has significant implications for a country where cancer is the leading cause of death.115

Looking at the facts today, the United States remains the uncontested leader in biotechnologies with a significant lead in innovation and seven of the ten most valuable life science companies.116 But that misses the bigger picture: since China listed biotech as one of the key arenas for national development under “Made in China 2025,” it has seen significant investment, reform, and growth in its biotech workforce. As summarized by a recent Nature article, “China’s life science companies are still innovating…with proactive government support, a billion-patient market and a motivated workforce, they just might challenge the hegemony of the U.S. biotech sector.”117

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116 Martin Wolf, “China is Wrong to Think the US Faces Inevitable Decline,” Financial Times, April 27, 2021, https://www.ft.com/content/8336169e-d1a8-4be8-b143-308e5b52e355

In the race to harness green energy, the U.S. has been the primary inventor of new technologies over the past two decades, but China has taken the lead in manufacturing and deploying those technologies, allowing it to dominate multiple links of the green energy supply chain. Indeed, as energy geopolitics expert Daniel Yergin stated, “In green energy, China has already reached the ‘Made in China 2025’ goal of a dominant role in this century’s new industries.”

The expansion of green energy in the global energy mix promises to be as disruptive in the 21st century as oil was in the 20th century. Financial markets already reflect these realities: clean energy investments reached $500 billion for the first time last year and, according to Goldman Sachs, will total $16 trillion over the next decade (more than three times the projected investments in new oil and gas by 2030). BlackRock’s Larry Fink in his 2020 CEO letter stated that “climate change has become a defining factor in companies’ long-term prospects and in the near future,” while the E.U. Commission for Climate Action has warned that “those who don’t embrace the clean-energy transition will be losers in the future.”

China has sprinted ahead of the U.S. and other countries to dominate the key links of the green tech supply chain, including equipment manufacturing, raw materials, and energy storage. Exploiting its status as the...
workshop of the world, China is now the dominant manufacturer of equipment for generating renewable energy. From producing less than 1% of solar panels in 2000, China now supplies 70% of solar panels globally. By comparison, in a stunning reversal, America’s share fell from 30% in 2000 to less than 1% today. Four of the world’s top ten wind turbine producers are Chinese and control 40% of the global market, versus 12% for the U.S. These advantages in manufacturing have positioned China as the largest producer of solar and wind energy, with more than three times the capacity of the United States in solar and two times in wind.

As the World Economic Forum has recognized, the “shift to zero-emission energy generation and transport means a new set of elements will become key.” In these new elements, China has a near-monopoly over several of the key inputs necessary for solar panels, batteries, and other green tech, including chemical lithium (50% of global production), polysilicon (60%), rare earth metals (70%), natural graphite (70%), cobalt refining (80%), and rare earths refining (90%). And where China lacks resources domestically, it has secured them overseas. Chinese companies own 8 of the 14 largest cobalt mines in the Democratic Republic of the Congo (accounting for 30% of global output) and a 51% stake in the world’s largest lithium reserve (which, combined with other assets, makes China the largest producer of

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hard-rock lithium at over 50% of global production). Meanwhile, the U.S. imports 40% of its lithium, 80% of its cobalt, and 100% of its graphite. It could take 20–30 years just for the U.S. to catch up with China in sourcing raw materials.

In energy storage, Bloomberg’s New Energy Outlook estimates that China controls 80% of battery raw material refining, 77% of cell capacity, and 60% of battery component manufacturing. Its assessment states that “Chinese manufacturers, like CATL, have come from nothing to being world-leading in less than 10 years,” while the “U.S. languishes in sixth place in 2020.” Over the next ten years, nearly 75% of new lithium-ion battery plants will be built in China. And as the world’s largest producers of hydrogen, China and the E.U. both lead in green hydrogen development—the two collectively spend $2 billion annually in R&D, more than ten times the Department of Energy’s $150 million annual allocation.

Together, these advantages along every link of the green energy supply chain position China as the global leader for the foreseeable future. Indeed, this can be seen in the best example of green tech today: electric vehicles (EVs). China has already become both the top producer of and market for EVs, with 1.3 million EVs sold in 2020 (more than 40% of global sales) versus 300,000 in the U.S. This rapid growth has increased China’s share of EVs from 20% of America’s in 2013 to 200% today. By 2028, China will be making nearly six EVs for each one the U.S. makes.

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130 Ben Foldy and Rebecca Elliot, “Shift to Electric Vehicles Spurs Bid to Make More Batteries in U.S.; “China Dominates the Lithium-Ion Battery Supply Chain, but Europe is on the Rise,” BloombergNEF, September 16, 2020, https://about.bnef.com/blog/china-dominates-the-lithium-ion-battery-supply-chain-but-europe-is-on-the-rise/.


China’s EV charging stations exceed one million nationwide and were being installed at a rate of a thousand a day in 2019, while the U.S. has only installed 100,000 total.\textsuperscript{134} Chinese firm BYD dominates 90% of the electric bus market, supplying buses to cities like Los Angeles and New York.\textsuperscript{135} Recognizing that China is on track to dominate the future of EVs, President Biden has declared, “We ought to be the single most significant suppliers of electric buses and vehicles in the world before it’s over. Right now, we’re running way behind China.”\textsuperscript{136}

America’s edge lies in breakthrough innovations. While China’s advantages in process engineering have allowed it to lead in scaling and deploying green tech, as former Secretary of Energy Ernest Moniz states, “the U.S. has shown over many decades an unparalleled capacity to nurture energy innovation.”\textsuperscript{137} In carbon capture and sequestration (CCS) technology, the U.S. is home to more than half of the world’s large-scale CCS facilities and produces the most CCS publications.\textsuperscript{138} Last December, QuantumScape, an American startup, showcased lithium-metal batteries which are safer, longer-lasting, and can increase electric vehicles’ range by more than 80%, an achievement which the MIT Technology Review recognized as one of the top 10 technologies of 2021 alongside mRNA vaccines and GPT-3.\textsuperscript{139} And while China is now its biggest market, Tesla is undeniably a product of America’s innovation ecosystem and one of

\begin{thebibliography}{99}


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The Great Tech Rivalry: China vs the U.S.

As countries commit to more ambitious Nationally Determined Contributions under the Paris Agreement to combat the climate crisis, developing new green energy technologies will become increasingly important for China and the U.S., the world’s first and second largest carbon emitters. As a challenge no one single country can solve alone, avoiding climate-induced Mutually Assured Destruction will require both the U.S. and China to start with green energy transitions domestically and then offer their respective advantages to expand the green energy supply chain globally. But in this effort to build a low-carbon global economy, the undeniable reality is that—even as it expands its coal capacity and carbon emissions—China will be a senior partner as the biggest producer, user, and exporter of green energy technologies which the U.S., the E.U., and others will depend on for their own green energy transitions.

**Today’s Green Energy is Red**

China dominates key links of the green energy supply chain

Source: See Footnotes 123, 124, 127, 130, and 132

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Prevailing in the U.S.-China technological rivalry requires more than leadership in just one arena. The foundation of national success in these fields is the operating environments in which companies, institutions, and individuals work. Key among these are the science and technology talent pipeline, R&D ecosystem, and national policies.

As observed by former Lockheed Martin CEO Norman Augustine, “The lack of human investment is the longer-term threat [to U.S. technological dominance], and it’s rather ironic we have the world’s finest research universities by and large and yet our primary and secondary education system is simply not competitive.”

By total number of undergraduate university degrees in science and engineering, America was the global leader in 2000 with over 500,000 while China stood at just under 360,000. Today, China graduates four times as many STEM students as the United States (1.3 million vs. 300,000) and three times as many computer scientists (185,000 vs. 65,000).

In international science and technology rankings for K-12 students, China consistently outscores the United States in math and science—in 2018, China’s PISA scores, which assesses math, science, and reading, were ranked number one while the U.S. ranked 25th. Of every ten computer science PhDs graduating in the United States today, three

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142 Key sources consulted in the development of this section include: (i) Norman Augustine, former Chairman and CEO of Lockheed Martin Corporation, Under Secretary of the U.S. Army, and Chairman of the National Academy of Engineering. (ii) The American Academy of Arts and Sciences, an international learned society and independent policy research center that convenes the world’s leading scientists, scholars, artists, businesspeople, and public leaders to address critical challenges facing our global society. (iii) CSET. (iv) The National Security Commission on Artificial Intelligence.


are American and two are Chinese. Three decades ago, only one of every twenty Chinese students studying abroad returned home. Now, four of every five do. And although America has historically benefited from its ability to attract talent from a global pool of 7.9 billion (with almost half of all U.S. Fortune 500 companies founded by immigrants or their children), as the National Security Commission on Artificial Intelligence recognized, “Competition for international students has accelerated…For the first time in our lifetime, the United States risks losing the competition for talent on the scientific frontiers.”

At the beginning of the century, America was number one in R&D expenditures, spending $270 billion in current purchasing power parity, followed by the E.U. at $180 billion. That same year China’s expenditure was only 12% of America’s at $33 billion. But by 2020, China rose to number two with 90% of America’s expenditure. On its current trajectory, China will overtake the U.S. within the next decade. Indeed, although the U.S. maintains a strong position in long-term drivers of scientific development (where the U.S. accounts for 60% of global spending on basic research to China’s 20%), China has focused intensely on turning scientific developments into commercial products and now spends almost $70 billion more annually than the U.S. in experimental development. While six American companies top the list of the world’s 10 most valuable tech companies, six Chinese companies lead the list of the 10 most valuable unicorns

146 Raw numbers do not necessarily capture quality of STEM PhDs, which America likely leads in. But despite 10 of the top 20 universities being in the U.S., China’s Tsinghua University is number one in the world in computer science and other Chinese universities will likely join the ranks of the world’s top S&T institutions by the end of the decade. Moreover, in developing commercial solutions, quantity is arguably more important than quality, especially at the PhD level. See Remco Zwetsloot et al., “China is Fast Outpacing U.S. STEM PhD Growth”; Martin Wolf, “China is Wrong to Think the US Faces Inevitable Decline.”


Comparing national policies, America faces several challenges, including a cultural preference for privacy over security relative to China; companies wary of working with the Defense Department and intelligence agencies; dysfunctional public policies inhibiting recruitment and immigration; laws that make it difficult to compile large datasets; pushback against government R&D spending; and the prospect of further regulations and antitrust action against companies that are America’s national champions.\footnote{Although privacy concerns limit America’s technological development in certain areas, new advancements in privacy technology and a “commitment to privacy protection” may also offer strategic advantages. See Jason Matheny, “The Future of Data Science,” keynote address for the National Academies of Sciences, Engineering, and Medicine, November 4, 2020, https://cset.georgetown.edu/article/the-future-of-data-science/.} Moreover, the continued outsourcing of manufacturing and engineering poses a long-term threat to American technological prowess.\footnote{Venkatesh Narayanamurti, the Founding Dean of Harvard’s School of Engineering and Applied Sciences, has recognized that by offshoring manufacturing, “the United States also has put at risk its greatest asset: the return on its intellectual capital. We have let China learn by doing, South Korea innovate by manufacturing, India build new capabilities in design and research and development—much of it on the back of initial American innovation.” See Venkatesh Narayanamurti, “Exporting America’s Future,” Los Angeles Times, March 26, 2012, https://www.latimes.com/opinion/la-xpm-2012-mar-26-la-oe-nara-research-development-jobs-20120326-story.html.} As described by former Intel CEO and Silicon Valley legend Andy Grove, “Without scaling, we don’t just
lose jobs—we lose our hold on new technologies. Losing the ability to scale will ultimately damage our capacity to innovate.”\(^{158}\) Yet the U.S. continues to have many advantages, including a greater number of top research universities; tech companies that are more accountable to the public; a more transparent form of government allowing for popular participation; a wider range of technology partnerships abroad; a persistent appeal to high-skilled migrants; an unparalleled advantage in emerging technologies including aeronautics, medicine, and nanotech; and a tradition of protecting and enabling blue-sky innovators.

Recognizing these opportunities and challenges, the Biden Administration’s “American Jobs Plan” aimed to invest hundreds of billions of dollars in semiconductor manufacturing, clean energy, biotechnology, and other critical technologies to “lay the foundation for the future breakthroughs that over time yield new businesses, new jobs, and more exports.”\(^{159}\) However, in passing its version of Biden’s jobs plan, Congress slashed the $2.3 trillion investment in half and removed key technology provisions.\(^{160}\)

China’s advantages begin with a central leadership that understands the stakes of the tech competition and aims for China to “enter the forefront of innovative countries” by 2035; an unprecedented national strategy for acquiring overseas technologies (through investments, talent programs, open-source S&T collection, intellectual property theft, and academic espionage); competitive provincial governments that execute these strategies through local initiatives like high-tech parks; scale of funding; and data collected by companies and government in a society that prioritizes security over privacy.\(^{161}\) China’s government, laws and regulations, national strategies, and deep military-civil fusion are all green lights for its advance in key

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emerging technologies.\textsuperscript{162} Wherever the Chinese government can protect companies in its domestic market, support national champions through subsidies and access to government data, and enable corporations to lead, it does. As a result, China’s tech ecosystem may be on par with Silicon Valley by 2025 “in terms of dynamism, innovation, and competitiveness.”\textsuperscript{163}

But can this trajectory be maintained? China’s rise today could mirror that of 1980s Japan, which was widely expected to overtake the U.S. as the world’s leading economic and technological powerhouse by the 1990s. While the cases share some similarities (such as slowing productivity growth, highly-centralized development strategies, and heavy state interventions creating tensions between innovation and market inefficiencies), the historical analogy is less convincing when examining the key drivers of China’s technological rise.\textsuperscript{164} Measured by purchasing power parity, China’s GDP is already 15% larger than America’s and, as the substructure of national power, has allowed it to continuously increase R&D spending over the past two decades, reaching 90% of U.S. spending today. By comparison, neither Japan’s GDP nor R&D spending ever reached 50% of America’s.\textsuperscript{165}

The differences between the two are even more stark when looking at their respective tech innovation ecosystems. In the 1980s, Japan graduated 80,000 STEM students annually, had a fledgling venture capital (VC) industry with 100 firms, and spent $900 million in annual VC investments.


Today, China graduates 1.3 million STEM students annually, is home to the world’s second largest VC market with over 3,500 firms, and spent $105 billion in venture investments in 2018 (95% of U.S. VC spending).\(^{167}\)

And, most strikingly, Japan’s technological ambitions were hampered by “Galápagos syndrome”: its innovative technologies were developed in isolation and highly-specialized for the domestic market but struggled to compete overseas.\(^{168}\) By contrast, China’s technological growth has been deeply integrated throughout the world, as evidenced by its worldwide rollout of 5G. According to Andy Grove, its capacity to “scale up” the innovations of others has allowed China to rise in the tech value chain from manufacturing to R&D to standards-setting.

In sum, although the U.S. has led the past half-century of technological innovation and still retains dominance in several other technological fields, China has emerged as a serious peer competitor in the foundational technologies of the 21st century whose applications promise to be transformative in arenas from intelligence and military power to economic growth and governance.


As the 2020 Report of the American Academy of Arts & Sciences “The Perils of Complacency” concludes: “Given the enormous scale and rate of progress of Asia, particularly China, the United States will find that reversing its own downward slide will be very difficult...If we ignore this issue, declines in the economic well-being of our citizenry and our ability to influence world affairs will be inevitable.”

**U.S. and China Gross Expenditures in R&D**

*Source: AMACAD “The Perils of Complacency”, OECD Main Science and Technology Indicators*

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<td>2000</td>
<td>$270bn</td>
<td>$30bn</td>
</tr>
<tr>
<td>2010</td>
<td>$500bn</td>
<td>$250bn</td>
</tr>
<tr>
<td>2020</td>
<td>$640bn</td>
<td>$580bn</td>
</tr>
</tbody>
</table>

*In billions U.S. 2020 dollars*

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