AVOIDING GREAT POWER WAR PROJECT

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

Graham Allison
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Karina Barbesino
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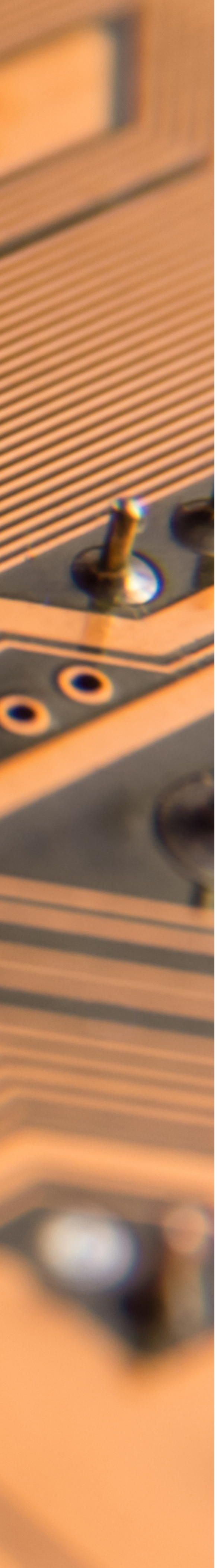
MADE IN CHINA



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

1 National Research Council, *Harnessing Science and Technology for America's Economic Future: National and Regional Priorities*, 1999, https://www.nap.edu/read/9456/chapter/11.

2 Bruce Nelan, "How the World Will Look in 50 Years," Time, October 15, 1992, http://content.time.com/time/subscriber/article/0,33009,976739-3,00.html.

3 Regina M. Abrami, William C. Kirby, and F. Warren McFarlan, "Why China Can't Innovate," Harvard Business Review, March 2014, https://hbr.org/2014/03/why-china-cant-innovate.

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.

4 *Shanzhai* (山寨) is a Chinese neologism meaning counterfeit or copycat, especially relating to technology. Rather than being purely negative, shanzhai culture also encompasses incremental innovations that can even result in superior products to the original. See Wy Cheng, "The Hidden Benefits of China's Counterfeiting Habit," The Diplomat, July 8, 2016, https://thediplomat.com/2016/07/the-hidden-benefits-of-chinas-counterfeiting-habit/; Matt Asay, "Microsoft Gives Up On Charging for Windows in China," TechRepublic, March 20, 2015, https://www.techrepublic.com/article/microsoft-gives-up-on-charging-for-windows-in-china/.

5 Burns doubled down on this statement when he announced the creation of a new CIA China mission center alongside a new Transnational and Technology mission center in October 2021. Julian E. Barnes, "C.I.A. Reorganization to Place New Focus on China," The New York Times, October 7, 2021, https://www.nytimes.com/2021/10/07/us/politics/cia-reorganization-china.html; "Transcript: NPR's Full Conversation with CIA Director William Burns," NPR, July 22, 2021, https://www.npr.org/2021/07/22/1017900583/transcript-nprs-full-conversation-with-cia-director-william-burns.

6 Daniel Slotta, "Production of cell phones in China from September 2020 to September 2021," Statista, October 20, 2021, https://www.statista.com/statistics/226434/production-of-cell-phones-in-china-by-month/; Daniel Workman, "Computer Device Exports by Country," World's Top Exports, July 27, 2021, https://www.worldstopexports.com/computer-device-exports-country/; Yilei Sun and Brenda Goh, "China leads auto industry recovery as sales top expectations," Reuters, December 20, 2020, https://www.reuters.com/article/us-china-autos/china-leads-auto-industry-recovery-as-sales-top-expectations-idUSKBN28L06P; Felix Richter, "These are the top 10 manufacturing countries in the world," World Economic Forum, February 25, 2020, https://www.weforum.org/agenda/2020/02/countries-manufacturing-trade-exports-economics/.; "Country Profile," UN Statistics Division, December 2019, Accessed November 2021, https://unstats.un.org/unsd/snaama/CountryProfile.

7 In his testimony to the Senate Armed Service Committee, Eric Schmidt stated that "a priority shortlist should include AI, 5G, microelectronics, biotechnology, and quantum computing." His assessment has been echoed not only by the Director of the National Counterintelligence and Security Center, Michael Orlando, who singled out AI, semiconductors, biotechnology, quantum computing, and autonomous systems as key technologies, but also by the Department of Defense, which recently examined the military significance of these technologies as well as alternative energy. See "Military and Security Developments Involving the People's Republic of China," Department of Defense, November 3, 2021, https://media.defense.gov/2021/Nov/03/2002885874/-1/-1/0/2021-CMPR-FINAL.PDF; Kate O'Keeffe, "Counterintelligence Head Narrows Focus to Five Technologies Critical to U.S. Dominance," Wall Street Journal, October 22, 2021, https://www.wsj.com/articles/counterintelligence-head-narrows-focus-to-five-technologies-critical-to-u-s-dominance-11634907600; Kelley M. Sayler, "Emerging Military Technologies: Background and Issues for Congress," Congressional Research Service, October 21, 2021, https://sgp.fas.org/crs/natsec/R46458.pdf; Eric Schmidt, "Emerging Technologies and Defense: Getting the Fundamentals Right," testimony for the Senate Committee on Armed Services, February 23, 2021, https://www.armed-services.senate.gov/imo/media/doc/Schmidt_02-23-21.pdf.

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."[8] 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.[9]

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."[10] 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."[11]

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.

8 "(Authorized Release) Xi Jinping: Speeches at the 20th Academician Conference of the Chinese Academy of Sciences, the 15th Academician Conference of the Chinese Academy of Engineering, and the 10th National Congress of the Chinese Association for Science and Technology," Xinhua, May 28, 2021, http://www.xinhuanet.com/politics/2021-05/28/c_1127505377.htm.

9 "(Authorized Release from Two Sessions) The 14th Five Year Plan and 2035 Long-Term Development Objectives," Xinhua, March 5, 2021, http://www.xinhuanet.com/politics/2021lh/2021-03/05/c_1127172897.html; "(Authorized Release) Proposal of the Central Committee of the Chinese Communist Party on Drawing Up the 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2030," Xinhua, November 3, 2020, http://www.xinhuanet.com/politics/zywj/2020-11/03/c_1126693293.htm.

10 Eric Schmidt, "Losing Ground: U.S. Competitiveness in Critical Technologies," testimony for the House of Representatives Committee on Science, Space, and Technology, January 29, 2020, https://science.house.gov/hearings/losing-ground-us-competitiveness-in-critical-technologies.

11 Eric Schmidt, "Eric Schmidt: I Used to Run Google. Silicon Valley Could Lose to China," New York Times, February 27, 2020, https://www.nytimes.com/2020/02/27/opinion/eric-schmidt-ai-china.html.

- 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."

12 For an overview of how America's dominant position in 4G benefited the U.S., see "How America's 4G Leadership Propelled the U.S. Economy," Recon Analytics, April 16, 2018, https://api.ctia.org/wp-content/uploads/2018/04/Recon-Analytics_How-Americas-4G-Leadership-Propelled-US-Economy_2018.pdf.

AI[13]

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."[14] 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.[15] 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.[16] This spending generates a treasure trove of granular data about individual consumer behavior that can be used to develop other fintech applications,

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.

14 Graham Allison and Eric Schmidt, "Is China Beating the U.S. to AI Supremacy?" Belfer Center for Science & International Affairs, August 2020, https://www.belfercenter.org/publication/china-beating-us-ai-supremacy; Eric Schmidt, "The AI Revolution and Strategic Competition with China," Project Syndicate, August 30, 2021, https://www.project-syndicate.org/commentary/ai-revolution-competition-with-china-democracy-vs-authoritarianism-by-eric-schmidt-2021-08?barrier=accesspaylog.

15 "iFLYTEK, Asia's AI Leader, Unveils iFLYTEK Translator 2.0, iFLYREC Series Voice-to-Text Products, AI Note and iFLYOS at CES 2019," Business Wire, January 6, 2019, https://www.businesswire.com/news/home/20190106005130/en/.

16 Nadia Schadlow and Richard Kang, "Financial Technology Is China's Trojan Horse," Foreign Affairs, January 13, 2021, https://www.foreignaffairs.com/articles/china/2021-01-13/financial-technology-chinas-trojan-horse; "Report on Payment System in China 2019," People's Bank of China, March 2020, http://www.gov.cn/xinwen/2020-03/17/5492275/files/53314a9224dd4b78b6dcafa3493da503.pdf; Ding Yi, "China's Mobile Payments Grew More Than 70% in Q4," Caixin, March 18, 2020, https://www.caixinglobal.com/2020-03-18/chinas-mobile-payments-grew-more-than-70-in-q4-101530159.html.

such as AI-driven assessments of individuals' credit-worthiness.[17] 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.[18] 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.[19]

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.[20] Of the world's top ten most valuable AI startups, seven are American and three are Chinese.[21]

Chinese investments in AI research and development have surged to American levels, and the results are beginning to show.[22] 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."[23] Last year, China overtook the U.S. for overall AI citations, with a 35% increase from 2019.[24] In AI's hottest subfield—deep

17 Aaron Klein, "China's Digital Payments Revolution," Brookings Institution, April 2020, https://www.brookings.edu/research/chinas-digital-payments-revolution/; Jasmine Enberg, "Global Mobile Payment Users 2019," eMarketer, October 24, 2019, https://www.emarketer.com/content/global-mobile-payment-users-2019.

18 However, the U.S. is a strong contender in computer vision—a field in which AI trains computers to "understand" the visual world—of which facial recognition is a subfield. See Dan Milmo, "Facebook to shut facial recognition system and delete 1bn 'faceprints,'" The Guardian, November 2, 2021, https://www.theguardian.com/technology/2021/nov/02/facebook-to-shut-facial-recognition-system-and-delete-1bn-faceprints; Anthony J. Bradley, "China is Dominating Computer Vision AI Venture Capital Investment," Gartner Blog Network on Gartner.com, January 22, 2020, https://blogs.gartner.com/anthony_bradley/2020/01/22/china-dominating-computer-vision-ai-venture-capital-investment/.

19 Eamon Barrett, "In China, Facial Recognition Tech Is Watching You," Fortune, October 28, 2018, https://fortune.com/2018/10/28/in-china-facial-recognition-tech-is-watching-you/.

20 Jackie Snow, "China's AI Startups Scored More Funding than America's Last Year," MIT Technology Review, February 14, 2018, https://www.technologyreview.com/2018/02/14/145616/chinas-ai-startups-scored-more-funding-than-americas-last-year/.

21 "The 10 Most Valuable Private AI Companies," CB Insights, October 27, 2020, https://www.cbinsights.com/research/most-valuable-private-ai-companies/.

22 For details on the military applications of China's gains in AI see Ryan Fedasiuk, Jennifer Melot, and Ben Murphy, "Harnessed Lightning: How the Chinese Military is Adopting Artificial Intelligence," CSET, October 2021, https://cset.georgetown.edu/wp-content/uploads/CSET-Harnessed-Lightning.pdf.

23 Katrina Manson, "US has already lost AI fight to China, says ex-Pentagon software chief," Financial Times, October 10, 2021, https://www.ft.com/content/f939db9a-40af-4bd1-b67d-10492535f8e0.

24 "2021 AI Index Report," Stanford Institute for Human-Centered Artificial Intelligence, March 2021, https://aiindex.stanford.edu/report/.

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]

25 However, the U.S. remains far ahead of China in the number of papers that receive "best paper" awards—a proxy for breakthrough papers—at major AI conferences. See Jeff Huang, "Best Paper Awards in Computer Science (since 1996)," Brown University Human-Computer Interaction Research Group, July 5, 2021, https://jeffhuang.com/best_paper_awards/; Carissa Schoenick, "China May Overtake U.S. in AI Research," Medium, March 13, 2019, https://medium.com/ai2-blog/china-to-overtake-us-in-ai-research-8b6b1fe30595.

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/.

27 "Stanford Question Answering Dataset," accessed November 2021, https://rajpurkar.github.io/SQuAD-explorer/.

28 "International Olympiad in Informatics Statistics," accessed November 2021, https://stats.ioinformatics.org/.

29 Remco Zwetsloot et al., "China is Fast Outpacing U.S. STEM PhD Growth," Center for Security and Emerging Technologies, August 2021, https://cset.georgetown.edu/wp-content/uploads/China-is-Fast-Outpacing-U.S.-STEM-PhD-Growth.pdf.

30 Remco Zwetsloot, James Dunham, Zachary Arnold, and Tina Huang, "Keeping Top AI talent in the United States: Findings and Policy Options for International Graduate Student Retention," CSET, December 2019, https://cset.georgetown.edu/wp-content/uploads/Keeping-Top-AI-Talent-in-the-United-States.pdf.

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.[31] Even so, the United States enjoys two advantages in human capital that Beijing cannot replicate.[32] First, half of the world's AI superstars work for U.S. companies.[33] Second, America can recruit from all the world's 7.9 billion people, while inherent insularity restricts China to its own population.[34]

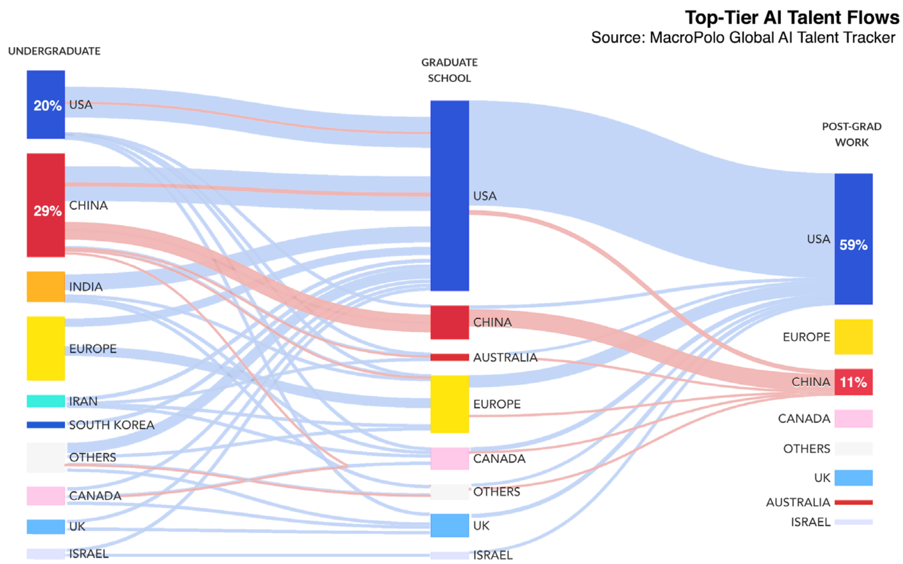
31 See Kai-Fu Lee's *AI Superpowers: China, Silicon Valley, and the New World Order* (Boston: Houghton Mifflin Harcourt, 2018).

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, Anna 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.

33 Ishan Banerjee and Matt Sheehan, "The Global AI Talent Tracker," MacroPolo, June 9, 2020, https://macropolo.org/digital-projects/the-global-ai-talent-tracker/.

34 Over half of graduate-level computer scientists working in the United States were born overseas. Additionally, over 80% of international AI PhD students stay in the U.S. for at least five years after graduating. Stay rates are especially high (exceeding 90%) among students from Taiwan, India, Iran, and China. Less than 20% of students who leave go to China. See Graham Allison, "America needs a 'Million Talents Program' now," The Hill, September 28, 2021, https://thehill.com/opinion/technology/574160-america-needs-a-million-talents-program-now; Jason Matheny, "Preparing the U.S. Economy for an AI Future Through Wise Policy Choices," testimony for the House Budget Committee, September 10, 2020, https://cset.georgetown.edu/publication/preparing-the-u-s-economy-for-an-ai-future-through-wise-policy-choices/; Remco Zwetsloot, James Dunham, Zachary Arnold, and Tina Huang, "Keeping Top AI talent in the United States: Findings and Policy Options for International Graduate Student Retention."

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."[35] 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.



35 "Final Report: National Security Commission on Artificial Intelligence," NSCAI.

5G[36]

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."[37] 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.[38] 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.[39] 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."[40]

Indeed, nearly all key indicators support projections that China will dominate the 5G future.[41] 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.

37 Milo Medin and Gilman Louie, "The 5G Ecosystem: Risks & Opportunities for DoD," Defense Innovation Board, April 3, 2019, https://innovation.defense.gov/Portals/63/Templates/Updated%20Meeting%20Documents/5G%20UNCLASS%20PAPER_190404_FINAL.pdf.

38 Hugo Yen, "Technology Factsheet: 5G," edited by David Simpson, Lindsay Gorman, and Amritha Jayanti, Belfer Center for Science and International Affairs, Spring 2020, https://www.belfercenter.org/publication/technology-factsheet-5g; "Creating Foundational 5G Technology: A Case Study of Qualcomm," Global Innovation Policy Center, October 28, 2020, https://www.qualcomm.com/media/documents/files/creating-foundational-5g-technology-a-case-study-of-qualcomm.pdf; "The Impact of 5G on the United States Economy," Accenture Strategy, February 2021, https://www.accenture.com/us-en/insights/high-tech/5g-economic-impact.

39 "Creating Foundational 5G Technology: A Case Study of Qualcomm," Global Innovation Policy Center; "The 5G Economy: How 5G will Impact Global Industries, The Economy, and You," MIT Technology Review, March 1, 2017, https://www.technologyreview.com/2017/03/01/153487/the-5g-economy-how-5g-will-impact-global-industries-the-economy-and-you/.

40 "The Mobile Economy China 2021," GSMA, 2021, https://www.gsma.com/mobileeconomy/wp-content/uploads/2021/02/GSMA_MobileEconomy2021_China_Eng-1.pdf.

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.[42] 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).[43]

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.[44] 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.[45] 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

42 Mid-band spectrum is the optimal wavelength range for 5G, balancing the benefits of the high-speed, low-coverage high-band spectrum and the high-coverage, low-speed low-band spectrum. America's 5G deployment has been limited by the FCC's slow allocation of mid-band spectrum. Even the recent record-breaking C-band auction to distribute mid-band spectrum was at best a minor success, with allocation not slated to be completed until the end of 2023. See John McCormick, Meghan Bobrowsky and Dan Strumpf, "Huawei, Ericsson or Nokia? Apple or Samsung? U.S. or China? Who's Winning the 5G Races," Wall Street Journal, October 12, 2021, https://www.wsj.com/articles/huawei-ericsson-nokia-apple-samsung-u-s-china-winning-5g-race-11634000044; Mike Dano, "A Direct Comparison: Tabulating 5G in the USA and China," Light Reading, December 16, 2020, https://www.lightreading.com/security/a-direct-comparison-tabulating-5g-in-usa-and-china/d/d-id/766196; Dan Strumpf, "U.S. vs. China in 5G: The Battle Isn't Even Close," Wall Street Journal, November 9, 2020, https://www.wsj.com/articles/u-s-vs-china-in-5g-the-battle-isnt-even-close-11604959200; "5G Mid-Band Spectrum Global Update," CTIA, March 23, 2020, https://www.ctia.org/news/report-5g-mid-band-spectrum-global-update; "The State of Mobile Internet Connectivity Report 2020," GSMA, September 2020, https://www.gsma.com/r/somic/.

43 Jamie Davies, "Nokia, Ericsson and Huawei Dominance Beginning to Fade – Analyst," Telecoms, August 4, 2020, https://telecoms.com/505872/nokia-ericsson-and-huawei-dominance-beginning-to-fade-analyst/.

44 Although the Trump Administration's campaign against Huawei successfully persuaded many key allies and partners to restrict Huawei equipment in their 5G networks, Huawei is still poised to be the biggest provider of 5G infrastructure globally and has secured 5G contracts in over 40 countries (or over half of the countries currently considering 5G deployments). Moreover, the anti-Huawei campaign has thus far had little effect on the U.S-China race to deploy domestic 5G networks. See David Sacks, "China's Huawei Is Winning the 5G Race. Here's What the United States Should Do to Respond," Council on Foreign Relations, March 29, 2021, https://www.cfr.org/blog/china-huawei-5g; Stu Woo and Dan Strumpf, "Huawei Loses Cellular-Gear Market Share Outside China," Wall Street Journal, March 7, 2021, https://www.wsj.com/articles/huawei-loses-cellular-gear-market-share-outside-china-11615118400.

45 In November 2020, Huawei sold its "budget brand" Honor to ensure that Honor would not be subject to U.S. sanctions and would be able to buy advanced semiconductors. Since then, Honor has launched higher-end phones and has risen as high as third in the ranks of smartphones firms in China after Xiaomi and Oppo. On the global market, U.S. sanctions significantly damaged Huawei's smartphone business: Huawei's market share dropped to 26% in Q2 2021 from 57% in Q2 2020. Xiaomi, Oppo, and Vivo, however, have filled much of the void left by Huawei; combined, they now have 47% of the global mobile phone market to Samsung and Apple's 33%. See Arjun Kharapal, "The smartphone brand that Huawei sold off is regaining market share in China," CNBC, September 29, 2021, https://www.cnbc.com/2021/09/29/honor-the-smartphone-brand-huawei-sold-off-regains-share-in-china.html; "Honor CEO Zhao Ming: Domestic Market Share Has Risen to 16.2%," Pandaily, September 23, 2021, https://pandaily.com/honor-ceo-zhao-ming-domestic-market-share-has-risen-to-16-2/; "Xiaomi becomes number two smartphone vendor for first time ever in Q2 2021," Canalys, July 15, 2021, https://www.canalys.com/newsroom/global-smartphone-market-q2-2021.

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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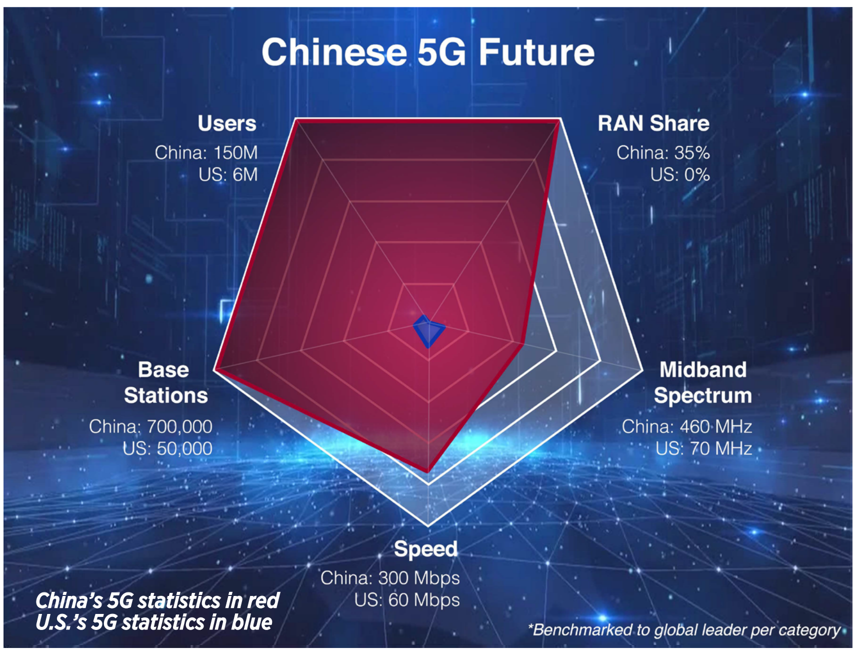
46 Rebecca Bellan, "Baidu gets green light for driverless robotaxi service in Beijing," Nikkei Asian Review, November 25, 2021, https://asia.nikkei.com/Business/China-tech/Baidu-gets-green-light-for-driverless-robotaxi-service-in-Beijing; Che Pan, "Baidu Will Offer First Paid Robotaxi Service in China Next Month, Letting People Hail Rides Without Drivers," South China Morning Post, April 29, 2021, https://www.scmp.com/tech/big-tech/article/3131617/baidu-will-offer-first-paid-robotaxi-service-china- next-month-letting.

47 As of 2020, the U.S. holds 14 of 58 chair or vice-chair positions in the 3GPP (3rd Generation Partnership Project—the body that sets mobile network technology standards), compared to 7 in 2012. Meanwhile, China holds 11 positions, compared to 9 in 2012. Delegates also voted for Qualcomm over Huawei to chair the most important 5G standards group (RAN1) in 2017 and again in 2019. See "China's High-Tech Development," USCC, November 2, 2018, https://www.uscc.gov/sites/default/files/2019-09/Chapter%204%20Section%201-%20Next%20Generation%20Connectivity_0.pdf; "Specifications Groups," 3GPP, accessed November 2021, https://www.3gpp.org/specifications-groups; Lindsay Gorman, "The U.S. Needs to Get in the Standards Game—With Like-Minded Democracies," Lawfare, April 2, 2020, https://www.lawfareblog.com/us-needs-get-standards-game—-minded-democracies.

48 Huawei has an 18% share of 5G patent families granted by the United States Patent and Trademark Office and the European Patent Office, as well as 23% of approved 5G technical contributions to 3GPP. See "Who Is Leading the 5G Patent Race?" iPlytics, February 2021, https://www.iplytics.com/wp-content/uploads/2021/02/Who-Leads-the-5G-Patent-Race_February-2021.pdf; Zeyi Yang, "China Holds 35% of Global 6G Patents, Government Report Says," Protocol, April 26, 2021, https://www.protocol.com/china/china-6g-patents.

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.



49 OpenRAN (ORAN) is a new, software-driven architecture for telecom infrastructure based on modular software built on commoditized hardware and multi-vendor interoperability, which challenges the end-to-end model of incumbent providers and encourages new market entrants specializing in specific areas of the 5G stack. ORAN trials are currently being conducted globally in the U.S., UK, Japan, and other countries. Chinese companies are also "deeply involved with OpenRAN technical specifications, product roadmap[s], and strategy." However, most operators have not committed to large-scale ORAN deployments in the near term. See "Fact vs Fiction: The 10 Parameters of OpenRAN," Strand Consult, April 30, 2021, https://strandconsult.dk/fact-vs-fiction-the-10-parameters-of-openran/; Dan Hays, "The Road to 2023: 5G's Tipping Point," RCR Wireless, March 3, 2021, https://www.rcrwireless.com/20210303/analyst-angle/the-road-to-2023-5g-tipping-point-analyst-angle; Carisa Nietsche and Martijn Rasser, "Create a bulwark against Chinese economic coercion: Advance open RAN in Europe," The Hill, February 15, 2021, https://thehill.com/opinion/technology/538865-create-a-bulwark-against-chinese-economic-coercion-advance-open-ran-in; "44 Chinese companies have joined the OpenRAN efforts, a strategy to reduce Huawei's presence in 5G," Strand Consult, December 17, 2020, https://strandconsult.dk/44-chinese-companies-have-joined-the-openran-effort-a-strategy-to-reduce-huaweis-presence-in-5g/.

50 Eric Schmidt, "U.S.'s Flawed Approach to 5G Threatens Its Digital Future," Financial Times, February 8, 2021, https://www.ft.com/content/dca96eaf-8262-42d8-a95f-d255642e9c7a.

51 "5G Use Cases for Vertical China 2021," GSMA and the China Academy of Information and Communications Technology, 2021, https://www.gsma.com/greater-china/wp-content/uploads/2021/02/5G-Use-Cases-for-Vertical-China-2021-EN.pdf.

Quantum Information Science[52]

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.[53] 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.[54]

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

52 Key sources consulted in the development of this section include: (i) Jake Taylor, former Assistant Director for Quantum Information Science at the Office of Science and Technology Policy and co-Founder of the Joint Center for Quantum Information and Computer Science. (ii) The United States-China Economic and Security Review Commission (USCC), an independent agency focused on the national security implications of bilateral trade and the economic relationship between U.S. and China. (iii) Scott Aaronson, a leading expert in quantum information science, the Director of the Quantum Information Center at the University of Texas at Austin, and the David J. Bruton Jr. Centennial Professor of Computer Science. (iv) John Costello, former Deputy Assistant Secretary of Intelligence and Security at the Department of Commerce and Senior Director at the U.S. Cyberspace Solarium Commission. (v) Elsa B. Kania, Adjunct Senior Fellow with the Technology and National Security Program at the Center for a New American Security. (vi) The Institute for Defense Analyses (IDA), a nonprofit corporation that provides scientific and technological expertise to assist national security decision-makers address urgent and challenging issues. For a comprehensive overview of China's ambitions and progress in quantum technologies, see Elsa B. Kania and John K. Costello, "Quantum Hegemony? China's Ambitions and the Challenge to U.S. Innovation Leadership," Center for a New American Security, September 12, 2018, https://s3.us-east-1.amazonaws.com/files.cnas.org/documents/CNASReport-Quantum-Tech_FINAL.pdf?mtime=20180912133406&focal=none.

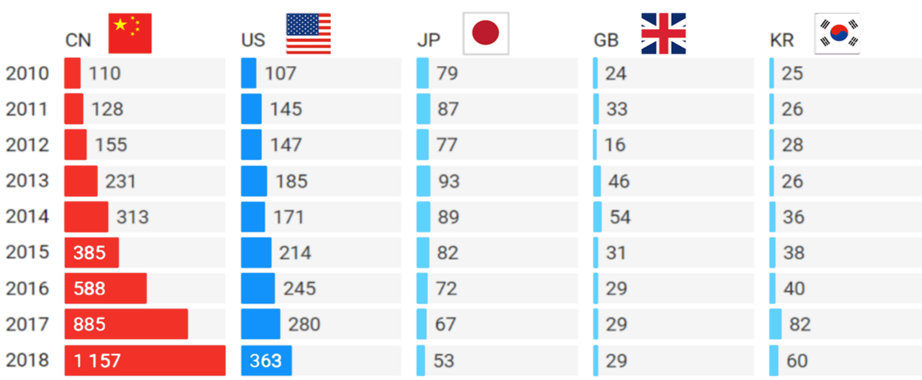
53 Quantum information technologies are based on the properties of quantum mechanics—like superposition and "spooky" quantum entanglement—which describe the counterintuitive behavior of matter at the subatomic level. When applying them to technologies, information is collected, generated, and processed using means that existing technologies cannot use for a variety of applications. For more information on definitions, how these properties work, and further discussion on their applications, see Akhil Iyer, "Tech Factsheets for Policymakers: Quantum Computing," edited by Emma Rosenfeld, Mikhail Lukin, William Oliver, and Amritha Jayanti, Belfer Center for Science and International Affairs, Spring 2020, https://www.belfercenter.org/sites/default/files/files/publication/QC_2.pdf; "Science & Tech Spotlight: Quantum Technologies," Government Accountability Office, May 2020, https://www.gao.gov/assets/710/707204.pdf; Scott Buchholz, Adam Routh, and Joe Mariani, "The Realist's Guide to Quantum Technology and National Security," Deloitte, February 6, 2020, https://www2.deloitte.com/us/en/insights/ industry/public-sector/the-impact-of-quantum-technology-on-national-security.html; Calla Cofield, "600-Year-Old Starlight Bolsters Einstein's 'Spooky Action at a Distance,'" Space.com, February 13, 2017, https://www.space.com/35676-einstein-spooky-action-starlight-quantum-entanglement.html.

54 However, akin to the transition from analog to digital, the full impact of the move from digital to quantum is impossible to imagine or predict, and for every new threat to national security that quantum technologies may bring, applications in health, finance, and industry are equally abundant. See Scott Buchholz, Adam Routh, and Joe Mariani, "The Realist's Guide to Quantum Technology and National Security."

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

Source: "Quantum Technologies Patents, Publications & Investments," Le Lab Quantique



55 Amit Katwala, "Why China's perfectly placed to be quantum computing's superpower," Wired, November 14, 2018, https://www.wired.co.uk/article/quantum-computing-china-us.

56 "Quantum technology is beginning to come into its own," Economist, March 11, 2017, https://www.economist.com/technology-quarterly/2017/03/09/quantum-technology-is-beginning-to-come-into-its-own.

57 Elsa B. Kania, "China's Quantum Future," Foreign Affairs, September 26, 2018, https://www.foreignaffairs.com/articles/china/2018-09-26/chinas-quantum-future; Michel Kurek, "Quantum Technologies Patents, Publications & Investments," Le Lab Quantique, September 2020, https://lelabquantique.com/wp-content/uploads/2020/09/QuantumTechnologiesPatPubInvLandscapes.pdf.

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."

59 "Report to Congress of the U.S.-China Economic and Security Review Commission," U.S.-China Economic and Security Review Commission, 2017, https://www.uscc.gov/annual-report/2017-annual-report-congress.

60 Matt Sheehan, "Beijing's Tech Ambitions: What Exactly Does It Want?" MacroPolo, April 13, 2021, https://macropolo.org/beijings-tech-ambitions-what-exactly-does-it-want/; Matt Ho, "Chinese scientists challenge Google's 'quantum supremacy' claim with new algorithm," South China Morning Post, March 16, 2021, https://www.scmp.com/news/china/science/article/3125539/chinese-scientists-challenge-googles-quantum-supremacy-claim-new.

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

61 In recent months, quantum computing has received increased attention from investors, with American firms PsiQuantum and IonQ becoming the first two quantum computing firms to go public. Madhumita Murgia, "Quantum computing comes out of shadows into public markets," Financial Times, October 21, 2021, https://www.ft.com/content/72b71d34-5804-4346-a10d-66f583e6300e; "Commercialising quantum computers," Economist, September 26, 2020, https://www.economist.com/science-and-technology/2020/09/26/commercialising-quantum-computers.

62 Akira Oikawa, Yuki Okoshi, and Yuki Misumi, "China emerges as quantum tech leader while Biden vows to catch up," Nikkei Asian Review, March 14, 2021, https://asia.nikkei.com/Spotlight/Datawatch/China-emerges-as-quantum-tech-leader-while-Biden-vows-to-catch-up#:~:text=Overall%20by%20country%20in%20quantum,as%20many%20as%20the%20U.S.; Peter Guest, "The subatomic age: Asia's quantum computing arms race," Nikkei Asian Review, May 5, 2020, https://asia.nikkei.com/Business/Technology/The-subatomic-age-Asia-s-quantum-computing-arms-race2.

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.[64] 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.[65] 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.[66] 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.[67]

64 An important distinction between the quantum computer created by the University of Science and Technology of China (named Jiuzhang) and Google's quantum computer is that the latter is based on superconducting materials while Jiuzhang uses photons. Thus, while Google's computer is, in principle, a universal quantum computer, Jiuzhang is not because even if scaled up, this method of computing cannot be used to create a conventional programmable computer. Regardless, Jiuzhang's claim is being taken as serious proof that quantum supremacy is possible via photonics and is therefore a possible pit stop toward universal quantum computing. More recently, Pan Jianwei claimed that the newly developed photonic quantum computer Jiuzhang 2 (as well as the new superconducting quantum computer Zuchongzhi 2) are significantly faster than Google's quantum computer for some calculations. Both Sycamore and Jiuzhang's claims have been subject to debate. IBM has disputed Google's claim, saying the problem could have been solved on a supercomputer in 2.5 days. Other researchers also contested the claim, saying a better classical algorithm could exist that would outperform the quantum algorithm. Skeptics of Jiuzhang's feat include notable experts such as Gil Kalai, Sergio Boixo, John Martinis, and Jelmer Renema. See Jake Taylor, "Learning from the automation of physics experiments," Belfer Center for Science and International Affairs, December 16, 2020, https://www.belfercenter.org/publication/learning-automation-physics-experiments; Yulin Wu et al. "Strong Quantum Computational Advantage Using a Superconducting Quantum Processor," Physical Review Letters, October 25, 2021, https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.127.180501; Qingling Zhu et al., "Quantum computational advantage via 60-qubit 24-cycle random circuit sampling," Science Bulletin, October 25, 2021, https://www.sciencedirect.com/science/article/abs/pii/S2095927321006733; Daniel Garisto, "China Is Pulling Ahead in Global Quantum Race, New Studies Suggest," Scientific American, July 15, 2021, https://www.scientificamerican.com/article/china-is-pulling-ahead-in-global-quantum-race-new-studies-suggest/; Cathal O'Connell, "Quantum computing for the qubit curious," Cosmos, July 5, 2019, https://cosmosmagazine.com/physics/quantum-computing-for-the-qubit-curious/; Philip Ball, "Physicists in China challenge Google's 'quantum advantage,'" Nature, December 3, 2020, https://www.nature.com/articles/d41586-020-03434-7; "Chinese Physicist Reportedly Said Team's Quantum Computer Bested Google's by a Million-fold," The Quantum Daily, September 11, 2020, https://thequantumdaily.com/2020/09/11/chinese-physicist-reportedly-said-teams-quantum-computer-bested-googles-by-a-million-fold/; James Griffiths, "The U.S. just moved ahead of China in quantum computing. But the race isn't over yet," CNN, October 24, 2019, https://www.cnn.com/2019/10/24/tech/china-quantum-computing-intl-hnk/index.html; Charlie Burton, "How China became a subatomic superpower with quantum technology," GQ, August 2, 2019, https://www.gq-magazine.co.uk/article/quantum-technology-china; Fintan Burke, "Qubit to get ahead: Germany is racing to catch up with quantum revolution," Science Business, August 4, 2020, https://sciencebusiness.net/news/qubit-get-ahead-germany-racing-catch-quantum-revolution.

65 Yulin Wu et al. "Strong Quantum Computational Advantage Using a Superconducting Quantum Processor"; Bob Yirka, "Chinese achieve new milestone with 56 qubit computer," Phys.org, July 12, 2021, https://phys.org/news/2021-07-chinese-milestone-qubit.html; Lauren Fuge, "China demonstrates most powerful quantum computer," Cosmos, July 6, 2021, https://cosmosmagazine.com/science/physics/china-demonstrates-most-powerful-quantum-computer/.

66 The team behind China's Jiuzhang say they measured using as many as 113 photons as qubits but averaged a more modest 43. See Daniel Garisto, "China Is Pulling Ahead in Global Quantum Race, New Studies Suggest," Scientific American, July 15, 2021, https://www.scientificamerican.com/article/china-is-pulling-ahead-in-global-quantum-race-new-studies-suggest/.

67 Chinese researchers do not regularly release information about the quantum volume of their computers, making direct comparisons difficult. Jeremy Kahn, "Honeywell teams with U.K. startup on a trio of quantum computing advances," Fortune, July 21, 2021, https://fortune.com/2021/07/21/honeywell-cambridge-quantum-computing-error-correction-quantum-volume-breakthroughs/.

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]

Quantum Publications (2010 - 2020)

Source: "Quantum Technologies Patents, Publications & Investments," Le Lab Quantique

	COUNTRY	TP	%TP	TC	%TC	CPP
1	USA	4,295	26.4%	108,128	44.8%	25.2
2	China	3,706	22.8%	38,611	16.0%	10.4
3	UK	1,428	8.8%	32,435	13.4%	22.7
4	Germany	1,400	8.6%	38,339	15.9%	27.4
5	Japan	1,106	6.8%	20,996	8.7%	19.0
	Total world	16,279		241,536		14.8

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

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] While Beijing has advanced programs in this field since the 1980s, Edward Snowden's 2013 leaks revealing U.S. covert

68 U.S. companies are pursuing four well-known approaches—superconducting qubits, trapped ion qubits, neutral atom qubits, and topological qubits—while Chinese companies lead in photonic qubits and have made gains in superconducting qubits. See Stephen Chen, "China launches world's fastest programmable quantum computers," South China Morning Post, October 26, 2021, https://www.scmp.com/news/china/science/article/3153727/china-launches-worlds-fastest-programmable-quantum-computers; Jonathan Tennenbaum, "China gaining fast on U.S. quantum computing lead," Asia Times, December 15, 2020, https://asiatimes.com/2020/12/china-gaining-fast-on-us-quantum-computing-lead/.

69 Peter Guest, "The subatomic age: Asia's quantum computing arms race" and Neil Savage, "Google's Quantum Computer Achieves Chemistry Milestone," Scientific American, September 4, 2020, https://www.scientificamerican.com/article/googles-quantum-computer-achieves-chemistry-milestone/; Amit Katwala, "Why China's perfectly placed to be quantum computing's superpower."

70 U.S.-China Economic and Security Review Commission, 2017.

71 "Why Should I Care about Quantum Computing?" Cipher Brief, March 19, 2020, https://www.thecipherbrief.com/why-should-i-care-about-quantum-computing; Stuart A. Wolf, Lance G. Joneckis, Steven Waruhiu, John C. Biddle, Olivia S. Sun, and Leonard J. Buckley, *Overview of the Status of Quantum Science and Technology and Recommendations for the DoD*, Institute for Defense Analyses, June 2019, https://www.ida.org/-/media/feature/publications/o/ov/overview-of-the-status-of-quantum-science-and-technology-and-recommendations-for-the-dod/d-10709.ashx; Jonathan Tennenbaum, "China gaining fast on U.S. quantum computing lead."

information gathering capabilities in China galvanized Beijing to accelerate progress in quantum communication—the "gold standard" for security.[72] As a result, in 2018 China registered over four times more patents than the U.S. in quantum communication and cryptography (517 to 117).[73] And since 2014, it has overtaken the U.S. and Europe (another leader in the field) in publications.[74]

China's milestones in quantum communication are impressive. In 2016, China launched Micius, the world's first quantum communication-enabled satellite.[75] Shortly afterward, Chinese scientists created a record-breaking quantum communication link between satellites and an earth station separated by more than 745 miles.[76] 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.[77]

Compared to quantum computing and communication, quantum sensing is a relatively mature field where real-world capabilities are already emerging.[78]

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72 Indeed, Pan Jianwei credited Snowden for China's determination to create more secure communications and motivating quantum research. Lee Billings, "China Shatters 'Spooky Action at a Distance' Record, Preps for Quantum Internet," Scientific American, June 15, 2017, https://www.scientificamerican.com/article/china-shatters-ldquo-spooky-action-at-a-distance-rdquo-record-preps-for-quantum-internet/; Elsa B. Kania and John K. Costello, "Quantum Hegemony? China's Ambitions and the Challenge to U.S. Innovation Leadership"; Jeanne Whalen, "The Quantum Revolution Is Coming, and Chinese Scientists Are at the Forefront," Washington Post, August 18, 2019, https://www.washingtonpost.com/business/2019/08/18/quantum-revolution-is-coming-chinese-scientists-are-forefront/; Peter Guest, "The subatomic age: Asia's quantum computing arms race."

73 Charlie Burton, "How China became a subatomic superpower with quantum technology."

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

75 Micius has already conducted remarkable experiments, including facilitating a video conference between Beijing and Vienna using quantum encryption, making it impossible to eavesdrop on. See "China launches quantum-enabled satellite Micius," BBC, August 16, 2016, https://www.bbc.com/news/world-asia-china-37091833; Lee Billings, "China Shatters 'Spooky Action at a Distance' Record, Preps for Quantum Internet"; Jeanne Whalen, "The quantum revolution is coming, and Chinese scientists are at the forefront."

76 China's ultimate goal is to launch a constellation of satellites and a nationwide fiber-optic quantum network that can securely transmit information (a 1,200 mile "backbone" network linking Beijing and Shanghai was already completed in 2017). China took a significant step towards this goal when Chinese researchers reliably transmitted single photons, "an essential resource for any quantum network," over 180 miles. See Daniel Garisto, "China Is Pulling Ahead in Global Quantum Race, New Studies Suggest"; Paul Smith-Goodson, "Quantum USA Vs. Quantum China: The World's Most Important Technology Race," Forbes, October 10, 2019, https://www.forbes.com/sites/moorinsights/2019/10/10/quantum-usa-vs-quantum-china-the-worlds-most-important-technology-race/#262ec1cd72de; "The World's First Quantum Communication Backbone was Launched and the First-ever Intercontinental Quantum Communication was Realized," QuantumCTek, September 29, 2017, http://www.quantum-info.com/English/News/progress/2017/2017/1007/392.html; Charlie Burton, "How China became a subatomic superpower with quantum technology."

77 Jeanne Whalen, "The quantum revolution is coming, and Chinese scientists are at the forefront."

78 Quantum sensing leverages quantum mechanics to measure properties like time, gravity, and electromagnetic fields with unprecedented accuracy and sensitivity. See Stuart A. Wolf et al., *Overview of the Status of Quantum Science and Technology and Recommendations for the DoD*; Michiel van Amerongen, "Quantum Technologies in Defence & Security," NATO Review, June 3, 2021, https://www.nato.int/docu/review/articles/2021/06/03/quantum-technologies-in-defence-security/index.html.

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.[79] 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.[80]

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."[81] Recent initiatives and increased funding have attempted to rectify some of these shortcomings, but more is needed to compete.[82] 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.[83] As Jason Matheny, the National Security Council's Coordinator for Technology and National Security, warns: "our advantage [in quantum technologies] is fragile."[84]

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79 Elsa B. Kania and Stephen Armitage, "Disruption Under the Radar: Chinese Advances in Quantum Sensing," Jamestown Foundation, August 17, 2017, https://jamestown.org/program/disruption-under-the-radar-chinese-advances-in-quantum-sensing/. For a discussion on why this field may not lead to a quantum surprise or dire strategic disadvantages, see Stuart A. Wolf et al., *Overview of the Status of Quantum Science and Technology and Recommendations for the DoD*.

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

81 John Costello, "Chinese Efforts in Quantum Information Science: Drivers, Milestones, and Strategic Implications," testimony for the U.S.-China Economics and Security Review Commission, March 16, 2017, https://www.uscc.gov/sites/default/files/John%20Costello_Written%20Testimony_Final2.pdf. Costello, along with Elsa B. Kania, have made significant contributions in this area of the U.S.-China competition through extensive reviews of open-source Chinese resources and writings. For more from these experts, see Elsa B. Kania and John Costello, "Quantum Leap (Part 1): China's Advances in Quantum Information Science," China Brief, December 5, 2016, https://jamestown.org/program/quantum-leap-part-1-chinas-advances-quantum-information-science-elsa-kania-john-costello/; Elsa B. Kania and John Costello, "Quantum Leap (Part 2): The Strategic Implications of Quantum Technologies," China Brief, December 21, 2016, https://jamestown.org/program/quantum-leap-part-2-strategic-implications-quantum-technologies/.

82 For example, the National Quantum Initiative Act, which was signed by President Trump in December 2018, promised increased funding and the creation of the Quantum Economic Development Consortium. Jake Taylor, "The Public-Purpose Consortium: Enabling Emerging Technology with a Public Mission," Belfer Center for Science and International Affairs, October 2020, https://www.belfercenter.org/sites/default/files/2020-10/Consortium%20Brief.pdf.

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

84 Gabriel Popkin, "OSTP Emphasizes Quantum Computing," APS News, February 2018, https://www.aps.org/publications/apsnews/201802/ostp.cfm.

Semiconductors[85]

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.[86] 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.[87] 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]."[88]

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

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.

86 Saif Khan, Alexander Mann, and Dahlia Peterson, "The Semiconductor Supply Chain: Assessing National Competitiveness," CSET, January 2021, https://cset.georgetown.edu/publication/the-semiconductor-supply-chain/; "Winning the Future: A Blueprint for Sustained U.S. Leadership in Semiconductor Technology," SIA, April 2019, https://www.semiconductors.org/wp-content/uploads/2019/04/SIA_Winning-the-Future_Refresh_FINAL1.pdf.

87 Josh Ye, "TSMC Founder Morris Chang Says China's Semiconductor Industry Still Five Years Behind Despite Decades of Subsidies," South China Morning Post, April 22, 2021, https://www.scmp.com/tech/big-tech/article/3130628/tsmc-founder-morris-chang-says-chinas-semiconductor-industry-still.

88 Mature technology nodes are those 28nm and above. They are widely used in everyday electronics, such as smart TVs, wireless connectivity chips, navigation systems, and edge computing. Mature technology nodes represented 61% of all semiconductors produced in 2019. Laurens Cerulus, "Chipmaker CEO Says Washington's Anti-China Tech Blockade Is a Bad Idea," Politico, April 23, 2021, https://www.politico.eu/article/europe-tech-sovereignty-china-peter-wennink-asml/; Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, "Strengthening the Global Semiconductor Supply Chain in an Uncertain Era," SIA/Boston Consulting Group (BCG), April 2021, https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf.

two notable successes.[89] 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.[90] 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.[91] 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.[92]

89 Steve Blank, "The Chip Wars of the 21st Century," War on the Rocks, June 11, 2020, https://warontherocks.com/2020/06/the-chip-wars-of-the-21st-century/.

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/051b2c80-d53b-410e-8e80-f433d25a82dd.

91 Before the Trump Administration's bans forced HiSilicon to downscale its operations its market share was 44% versus Qualcomm's 33%. China has also made significant advances in NAND (short-term memory) chips, with Yangtze Memory Technologies Company developing a new chip that outperformed competitors including Samsung and Micron. See Dylan Patel, "The Impending Chinese NAND Apocalypse – YMTC 128 Layer NAND Is The First Semiconductor Where China Is Technologically Competitive," SemiAnalysis, September 28, 2021, https://semianalysis.substack.com/p/the-impending-chinese-nand-apocalypse-e01; Josh Ye, "Huawei's HiSilicon Becomes First Mainland Chinese Chip company to Enter Top 10 in Global Sales, says IC Insights," South China Morning Post, May 7, 2020, https://www.scmp.com/tech/big-tech/article/3083314/huaweis-hisilicon-first-mainland-chinese-chip-company-enter-top-10.

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.[93] 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.[94] 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.[95] 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."[96] 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.[97]

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93 Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, "Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing," SIA/BCG, September 2020, https://www.semiconductors.org/turning-the-tide-for-semiconductor-manufacturing-in-the-u-s/.

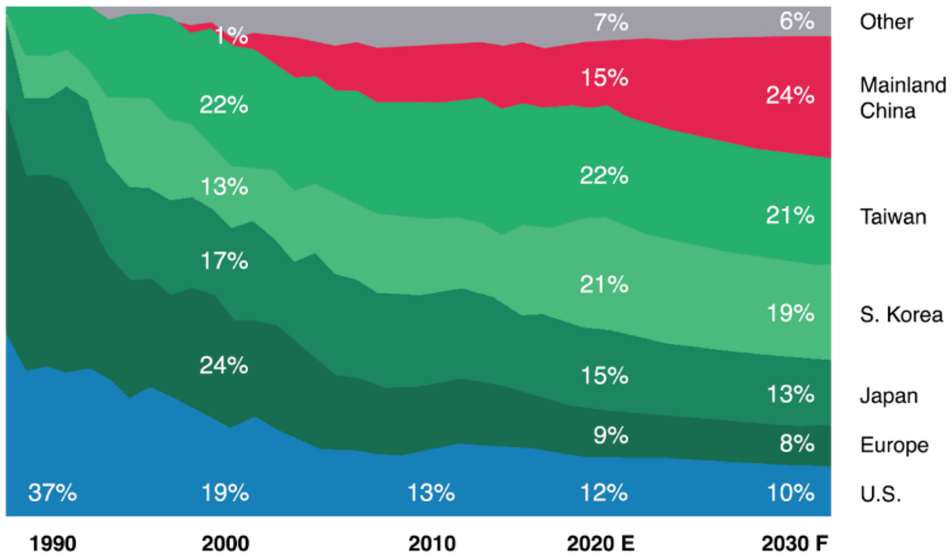
94 In 2020, the Chinese market represented 60% of Qualcomm's revenues, 30% of Broadcom's, and 25% of Intel's. See Will Hunt and Remco Zwetsloot, "The Chipmakers: U.S. Strengths and Priorities for the High-End Semiconductor Workforce," CSET, September 2020, https://cset.georgetown.edu/publication/the-chipmakers-u-s-strengths-and-priorities-for-the-high-end-semiconductor-workforce/; Sijia Jiang and Michael Martina, "Huawei's $105 Billion Business at Stake After U.S. Broadside," Reuters, May 16, 2019, https://www.reuters.com/article/us-usa-trade-china-huawei-analysis/huaweis-105-billion-business-at-stake-after-u-s-broadside-idUSKCN1SM123; Richard Beales, "Mountain of Debt Casts Shadow Over Broadcom-Qualcomm Deal," New York Times, November 6, 2017, https://www.nytimes.com/2017/11/06/business/dealbook/broadcom-qualcomm-debt.html.

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/.

96 Ina Fried and Mike Allen, "Intel CEO Calls for 'Moonshot' to Boost U.S. Role in Chipmaking," Axios, April 12, 2021, https://www.axios.com/intel-ceo-gelsinger-chipmaking-moonshot-boost-us-6d30b6eb-824d-4cbd-90c8-42150386d545.html.

97 Chad Brown, "How the United States Marched the Semiconductor Industry into Its Trade War with China," Peterson Institute for International Economics, December 2020, https://www.piie.com/sites/default/files/documents/wp20-16.pdf; "Surprising changes in semiconductor equipment market share in 2017," Semiconductor Digest, January 2018, https://sst.semiconductor-digest.com/2018/01/surprising-changes-in-semiconductor-equipment-market-share-in-2017/.

2030: China as the World's Top Semiconductor Producer



Share of Global Semiconductor Manufacturing (1990 - 2030 Forecast)
Source: Semiconductor Industry Association

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.[98]

98 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-rdns0/; 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."[99]

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.[100]

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-4dfd-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://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/190115_Lewis_Semiconductor_v6.pdf.

Biotechnology[101]

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."[102] 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.[103] 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.[104] 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%.[105] 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.[106] 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

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.

102 See Susan Hockfield, *The Age of Living Machines: How Biology Will Build the Next Technology Revolution* (New York: W. W. Norton & Company, 2019).

103 "China's Biotechnology Development: The Role of U.S. and Other Foreign Engagement," U.S.-China Economic and Security Review Commission, February 14, 2019, https://www.uscc.gov/sites/default/files/Research/U.S.-China%20Biotech%20Report.pdf.

104 "2021 tables: Countries/territories - life sciences," Nature Index, https://www.natureindex.com/annual-tables/2021/country/life-sciences; Gemma Conroy, "These are the 10 best countries for life sciences research," Nature Index, January 20, 2020, https://www.natureindex.com/news-blog/ten-best-countries-life-sciences-research-rankings.

105 "WIPO IP Statistics Data Center," World Intellectual Property Organization, accessed November 2021, https://www3.wipo.int/ipstats/index.htm.

106 John Wong, Chun Wu, Wen Xie, and Srikant Vaidyanathan, "Competing in China's Booming Biopharma Market," BCG, November 12, 2020, https://www.bcg.com/publications/2020/competing-in-chinas-biopharma-market.

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."[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).[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.[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.[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

107 "China launches world's largest genome-wide project," People's Daily, January 5, 2018, http://en.people.cn/n3/2018/0105/c90000-9312270.html.

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/.

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_hsac_emerging_technologies_biotechnology_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.

110 "ClinicalTrials.gov," National Institute of Health, accessed November 2021, https://clinicaltrials.gov/ct2/home.

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%).[111] Though much of China's biopharmaceutical growth has been driven by generic drugs, biosimilars, 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.[112] 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 preference of the international community is for American vaccines.[113]

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.[114] Within months, Johnson & Johnson (J&J) entered into a licensing agreement to access Legend's

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 and Approvals," AAPS Magazine, March 2021, https://www.aapsnewsmagazine.org/aapsnewsmagazine/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, 2019, https://itif.org/publications/2019/08/12/chinas-biopharmaceutical-strategy-challenge-or-complement-us-industry; "Top 1000+ Biofacility Index and Biomanufacturers Database," BioPlan, accessed November 2021, http://top1000bio.com/.

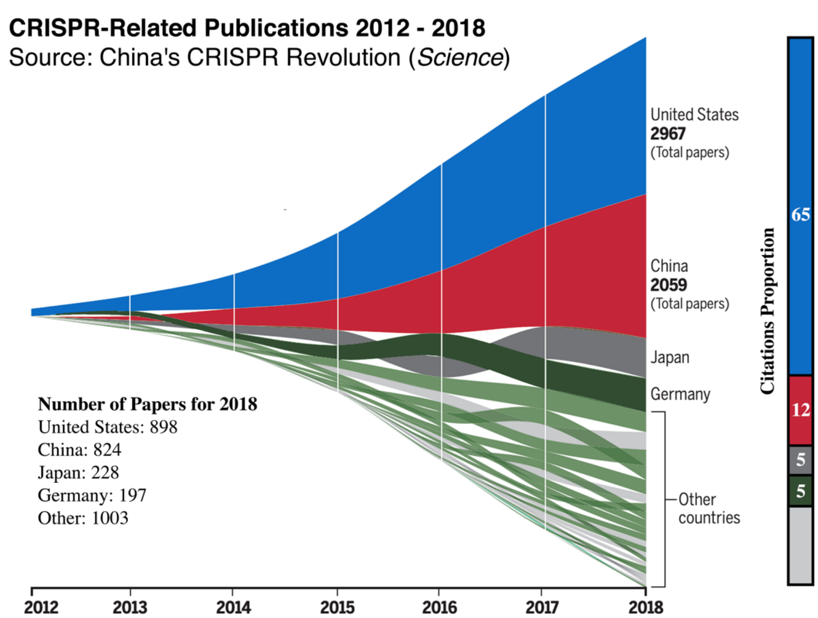
112 Carl Berrisford, "China's Biotech Revolution," UBS, August 2018, https://www.ubs.com/global/en/wealth-management/chief-investment-office/market-insights/regional-outlook/2018/china-biotech.html.

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 Sinovac COVID-19 Vaccine for Emergency Use and Issues Interim Policy Recommendations," World Health Organization, June 1, 2021, https://www.who.int/news/item/01-06-2021-who-validates-sinovac-covid-19-vaccine-for-emergency-use-and-issues-interim-policy-recommendations; "COVID-19 Vaccine Tracker," https://covid19.trackvaccines.org/vaccines/; Zeke Miller, "Biden doubles US global donation of COVID-19 vaccine shots," AP, September 22, 2021, https://apnews.com/article/united-nations-general-assembly-joe-biden-pandemics-business-united-nations-e7c09c1f896d83c0ed80513082787bd3.

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/30b5a944-3b57-11e8-b9f9-de94fa33a81e; "Janssen Enters Worldwide Collaboration and License Agreement with Chinese Company Legend Biotech to Develop Investigational CAR-T Anti-Cancer Therapy," Johnson & Johnson, December 21, 2017, https://johnsonandjohnson.gcs-web.com/news-releases/news-release-details/janssen-enters-worldwide-collaboration-and-license-agreement-0.

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]



115 The U.S. is making slow progress on this front—in October 2021, the FDA approved the first CAR T-cell therapy in the U.S. for adults with relapsed or refractory B-cell precursor acute lymphoblastic leukemia. See Mike Bassett, "FDA Oks First CAR T-Cell Therapy for Adult ALL," MedPage Today, October 4, 2021, https://www.medpagetoday.com/hematologyoncology/leukemia/94834; Jianshu Wei, Yelei Guo, Yao Wang, Zhiqiang Wu, Jian Bo, Bin Zhang, Jun Zhu, and Weidong Han, "Clinical Development of CAR T Cell Therapy in China: 2020 Update," Cellular & Molecular Immunology, September 30, 2020, https://www.nature.com/articles/s41423-020-00555-x.

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

117 Brady Huggett, "'Innovation' nation," Nature Biotechnology, October 29, 2019, https://www.nature.com/articles/s41587-019-0306-9?proof=t%252Btarget%253D.

Green Energy[118]

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."[119]

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).[120] 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."[121]

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

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118 Key sources consulted in the development of this section include: (i) Dr. Ernest Moniz, former U.S. Secretary of Energy and Director of the MIT Energy Initiative. (ii) Meghan O'Sullivan, North American Chair of the Trilateral Commission, Jeane Kirkpatrick Professor of the Practice of International Affairs at Harvard Kennedy School, and Director of the Geopolitics of Energy Project. (iii) Daniel Yergin, a leading energy geopolitics expert, Vice Chairman of IHS Markit, and author of several books including the Pulitzer Prize–winning *The Prize* (1991), *The Quest* (2011), and *The New Map* (2020). (iv) The Global Commission on the Geopolitics of Energy Transformation, an independent initiative launched during the 2018 International Renewable Energy Agency Assembly that examines how the large-scale shift to renewable energy is disrupting the global energy system. (v) Bloomberg New Energy Finance, a strategic research provider covering global commodity markets and the disruptive technologies driving the transition to a low-carbon economy.

119 See Daniel Yergin, *The New Map: Energy, Climate, and the Clash of Nations* (New York: Penguin Press, 2020).

120 Nathaniel Bullard, "Energy Transition's Half-Trillion-Dollar Year Is Even Better Than It Looks," Bloomberg, January 21, 2021, https://www.bloomberg.com/news/articles/2021-01-21/what-does-500-billion-for-clean-energy-mean-for-climate-change; Dan Murtaugh, "Goldman Sees $16 Trillion Opening as Renewables Pass Oil and Gas," Bloomberg, June 17, 2020, https://www.bloomberg.com/news/articles/2020-06-17/goldman-sees-16-trillion-opening-as-renewables-pass-oil-and-gas; "Entire $4.9 Trillion Investment in New Oil and Gas Is Incompatible with Global Climate Goals," Global Witness, April 23, 2019, https://www.globalwitness.org/en/press-releases/entire-49-trillion-investment-new-oil-and-gas-incompatible-global-climate-goals/.

121 Larry Fink, "A Fundamental Reshaping of Finance," BlackRock, January 2020, https://www.blackrock.com/uk/individual/larry-fink-ceo-letter; "Clean power is shaking up the global geopolitics of energy," Economist, March 17, 2018, https://www.economist.com/special-report/2018/03/15/clean-power-is-shaking-up-the-global-geopolitics-of-energy.

workshop of the world, China is now the dominant manufacturer of equipment for generating renewable energy.[122] From producing less than 1% of solar panels in 2000, China now supplies 70% of solar panels globally.[123] 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.[124] 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.[125]

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."[126] 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%).[127] 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

122 "A New World: The Geopolitics of the Energy Transformation," Global Commission on the Geopolitics of Energy Transformation, January 2019, http://geopoliticsofrenewables.org/report.

123 Sarah Ladislaw and Nikos Tsafos, "Beijing Is Winning the Clean Energy Race," Foreign Policy, October 2, 2020, https://foreignpolicy.com/2020/10/02/china-clean-energy-technology-winning-sell/.

124 "Vestas Still Rules Turbine Market, But Challengers Are Closing In," BloombergNEF, February 18, 2020, https://about.bnef.com/blog/vestas-still-rules-turbine-market-but-challengers-are-closing-in/.

125 "Renewable Capacity Statistics 2021," International Renewable Energy Agency, 2021, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_RE_Capacity_Statistics_2021.pdf.

126 Andrew Barron, "These Renewable Superpowers Control the Future of Energy," World Economic Forum, February 20, 2018, https://www.weforum.org/agenda/2018/02/meet-the-new-renewable-superpowers-nations-that-boss-the-materials-used-for-wind-and-solar.

127 Meghan O'Sullivan, Indra Overland, and David Sandalow, "The Geopolitics of Renewable Energy," HKS Faculty Research Working Paper Series RWP17-027, June 2017, https://www.hks.harvard.edu/publications/geopolitics-renewable-energy; Daniel Yergin, *The New Map: Energy, Climate, and the Clash of Nations*; "China Dominates the Global Lithium Battery Market," Institute for Energy Research, September 9, 2020, https://www.instituteforenergyresearch.org/renewable/china-dominates-the-global-lithium-battery-market/; Alistair MacDonald, "U.S. Faces Uphill Climb to Rival China's Rare-Earth Magnet Industry," Wall Street Journal, April 11, 2021, https://www.wsj.com/articles/u-s-faces-uphill-climb-to-rival-chinas-rare-earth-magnet-industry-11618133603; Ben Foldy and Rebecca Elliot, "Shift to Electric Vehicles Spurs Bid to Make More Batteries in U.S.," Wall Street Journal, January 26, 2021, https://www.wsj.com/articles/u-s-mounts-a-charge-to-take-on-china-the-king-of-electric-vehicle-batteries-11611658235; Teague Egan, "Beating China at the lithium game — Can the US Secure Supplies to Meet Its Renewables Targets?" Utility Dive, February 18, 2020, https://www.utilitydive.com/news/beating-china-at-the-lithium-game-can-the-us-secure-supplies-to-meet-its/572307/.

hard-rock lithium at over 50% of global production).[128] 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.[129]

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.[130] 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.[131]

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.[132] 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.[133]

128 Lithium giant Tianqi Lithium controlled 46% of global production in 2018, though recent financial struggles may decrease its share. Jiangxi Ganfeng Lithium also has significant stakes in mines in Australia, Chile, and other countries. See Tom Daly, "China's Tianqi Lithium posts best profit in almost 3 yrs," Reuters, October 29, 2021, https://www.reuters.com/world/china/chinas-tianqi-lithium-posts-best-profit-almost-3-yrs-2021-10-29/; Ying Lu, "Cobalt, Copper: China Strengthens Relations with DRC through Debt Relief and Belt and Road Initiative," Roskill, January 14, 2021, https://roskill.com/news/cobalt-copper-china-strengthens-relations-with-drc-through-debt-relief-and-belt-and-road-initiative/; Tom Mitchell and Jamie Smyth, "Chinese Lithium Producer Sells Minority Stake in Australian Mine," Financial Times, December 8, 2020, https://www.ft.com/content/4b639e28-6424-464c-bc9d-d7d71712156c.

129 "Lithium Data Sheet," United States Geological Survey, September 2020, https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-lithium.pdf.

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/.

131 "Road Map to a U.S. Hydrogen Economy," Fuel Cell and Hydrogen Energy Association, October 2020, https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+U.S.+Hydrogen+Economy+Full+Report.pdf.

132 Felix Richter, "Chart: Which Countries Have the Largest Electric Car Markets?" World Economic Forum, February 23, 2021, https://www.weforum.org/agenda/2021/02/electric-vehicle-market-global/; Roland Irle, "Global Plug-in Vehicle Sales Reached over 3,2 Million in 2020," EV Volumes, https://www.ev-volumes.com/news/86364/.

133 Keith Bradsher, "As Cars Go Electric, China Builds a Big Lead in Factories," New York Times, May 4, 2021, https://www.nytimes.com/2021/05/04/business/china-electric-cars.html.

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.[134] Chinese firm BYD dominates 90% of the electric bus market, supplying buses to cities like Los Angeles and New York.[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."[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."[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.[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.[139] And while China is now its biggest market, Tesla is undeniably a product of America's innovation ecosystem and one of

134 "China Electric Vehicle Charging Infrastructure Market - Growth, Trends, Covid-19 Impact, and Forecasts (2021 - 2026)," Mordor Intelligence, 2021, https://www.mordorintelligence.com/industry-reports/china-electric-vehicle-charging-infrastructure#:~:text=The%20Chinese%20electric%20vehicle%20charging,period%20(2020%20%2D%202025).&text=The%20collaboration%20between%20various%20automotive,developers%20is%20driving%20market%20growth.; "Alternative Fueling Station Locator," Department of Energy Alternative Fuels Data Center, accessed November 2021, https://afdc.energy.gov/stations/#/analyze?country=US&fuel=ELEC; Colin McKerracher, "EV Charging Data Shows Widely Divergent Global Path," BloombergNEF, April 15, 2021, https://about.bnef.com/blog/ev-charging-data-shows-widely-divergent-global-path/.

135 Scott Malcomson, "How China Became the World's Leader in Green Energy," Foreign Affairs, February 28, 2020, https://www.foreignaffairs.com/articles/china/2020-02-28/how-china-became-worlds-leader-green-energy.

136 David Shepardson, "Biden: U.S. Must Boost EV Production to Surpass China," Reuters, April 20, 2021, https://www.reuters.com/world/us/biden-kicks-off-electric-vehicle-push-with-south-caroline-plant-tour-2021-04-20/.

137 "Advancing the Landscape of Clean Energy Innovation," Breakthrough Energy, February 2019, https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5c5a24864e17b6106a7bf9ce/1549411488418/BE2442_Report_013119.pdf.

138 Lee Beck, "Carbon Capture and Storage in the USA: The Role of U.S. Innovation Leadership in Climate-Technology Commercialization," Global CCS Institute, January 16, 2020, https://www.globalccsinstitute.com/resources/publications-reports-research/carbon-capture-and-storage-in-the-usa-the-role-of-us-innovation-leadership-in-climate-technology-commercialization/; "Energy Department Ranked Global Leader in Carbon Capture and Storage Research," U.S. Department of Energy – Office of Fossil Energy and Carbon Management, October 15, 2019, https://www.energy.gov/fe/articles/energy-department-ranked-global-leader-carbon-capture-and-storage-research.

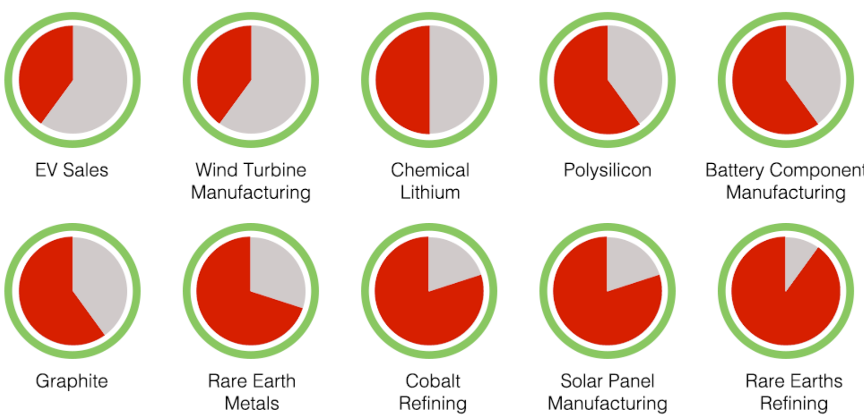
139 "10 Breakthrough Technologies 2021," MIT Technology Review, February 24, 2021, https://www.technologyreview.com/2021/02/24/1014369/10-breakthrough-technologies-2021/.

the top successes of the U.S. government's Advanced Research Projects Agency-Energy.[140]

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.[141]

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

140 Nathan Furr and Jeff Dyer, "Lessons from Tesla's Approach to Innovation," Harvard Business Review, February 12, 2020, https://hbr.org/2020/02/lessons-from-teslas-approach-to-innovation; Christina Nunez, "Tesla's Musk Promises to Halve Loan Payback Time to DOE, Jokes About 'Times' Feud," National Geographic, February 26, 2013, https://www.nationalgeographic.com/environment/article/teslas-musk-promises-to-halve-loan-payback-time-to-doe-jokes-about-times-feud.

141 With increasing coal consumption through 2025, China is projected to emit more greenhouse gases than all developed countries combined through 2030, and its pipeline for new coal-fired capacity in coming years is equivalent to the total energy capacity of the European Union. However, China's dominance of green energy technologies means that China will nonetheless be a key player in the transition to a cleaner global economy. See Leslie Hook, Camilla Hodgson, and Jim Pickard, "India and China weaken pledge to phase out coal as COP26 ends," *Financial Times*, November 13, 2021, https://www.ft.com/content/471c7db9-925f-479e-ad57-09162310a21a; Sara Schonhardt, "China's Greenhouse Gas Emissions Exceed Those of All Other Developed Countries Combined," Scientific American, May 6, 2021, https://www.scientificamerican.com/article/chinas-greenhouse-gas-emissions-exceed-those-of-all-other-developed-countries-combined/; "China Set for Massive Coal Expansion in Threat to Climate Goals," Bloomberg, November 20, 2019, https://www.bloomberg.com/news/articles/2019-11-20/china-set-for-massive-coal-expansion-in-threat-to-climate-goals.

Macro Drivers of the Tech Competition[142]

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."[143] 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).[144] 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.[145] Of every ten computer science PhDs graduating in the United States today, three

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.

143 "America at a Tipping Point: Science and Technology Opportunities for the Biden Administration," Rice University Baker Institute for Public Policy, March 31, 2021, https://www.bakerinstitute.org/events/2201/.

144 Graham Allison and Eric Schmidt, "Is China Beating the U.S. to AI Supremacy?" Belfer Center for Science and International Affairs, August 2020, https://www.belfercenter.org/sites/default/files/2020-08/AISupremacy.pdf; Graham Allison, "America second? Yes, and China's lead is only growing," The Boston Globe, May 22, 2017, https://www.bostonglobe.com/opinion/2017/05/21/america-second-yes-and-china-lead-only-growing/7G6szOUkTobxmuhgDtLD7M/story.html; Prashant Loyalka et al., "Computer science skills across China, India, Russia, and the United States," Proceedings of the National Academy of Sciences, April 2, 2019, https://www.pnas.org/content/116/14/6732.

145 Although PISA scores are not a perfect comparison as only top-performing Chinese provinces are evaluated, they nonetheless are a good indicator of China's rising STEM talent. PISA scores from areas like Beijing and Jiangsu are similar to those from Massachusetts and New York and from top-performing countries like Singapore and Estonia. See Jill Barshay, "What 2018 PISA international rankings tell us about U.S. schools," Hechinger Report, December 16, 2019, https://hechingerreport.org/what-2018-pisa-international-rankings-tell-us-about-u-s-schools/; Mark Schneider, "Strange Case of 'China' and Its Top PISA Rankings — How Cherry-Picking Regions to Take Part Skews Its High Scores," The 74, December 10, 2019, https://www.the74million.org/article/schneider-the-strange-case-of-china-and-its-top-pisa-rankings-how-cherry-picking-regions-to-take-part-skews-its-high-scores/.

are American and two are Chinese.[146] Three decades ago, only one of every twenty Chinese students studying abroad returned home. Now, four of every five do.[147] 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."[148]

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.[149] 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.[150] 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.[151] 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."

147 Nearly half of all current STEM doctoral students in the U.S. are from abroad, making the continued inflow and retention of foreign talent critical to America's future success. See Bruce Alberts and Venkatesh Narayanamurti, "Two Threats to U.S. Science," Science, May 17, 2019, https://science.sciencemag.org/content/364/6441/613.full; William C. Hannas and Huey-meei Chang, "China's Access to Foreign AI Technology," CSET, September 2019. https://cset.georgetown.edu/wp-content/uploads/CSET_China_Access_To_Foreign_AI_Technology.pdf.

148 "Final Report: National Security Commission on Artificial Intelligence," NSCAI; "Immigrant Founders of the Fortune 500," Center for American Entrepreneurship, 2018, http://startupsusa.org/fortune500/.

149 "The Perils of Complacency: America at a Tipping Point in Science & Engineering," American Academy of Arts & Sciences, September 2020, https://www.amacad.org/sites/default/files/publication/resources/Perils-of-Complacency_Full-Report_3.pdf.

150 China's gross domestic expenditure on R&D increased by 10% in 2020, reaching $580 billion (purchasing power parity adjusted). The U.S.'s estimated R&D spending was $660 billion in 2019 and decreased slightly in 2020 to an estimated $640 billion. See "Main Science and Technology Indicators, Volume 2020 Issue 2," OECD, March 19, 2021, https://www.oecd-ilibrary.org/science-and-technology/main-science-and-technology-indicators/volume-2020/issue-2_0bd49050-en; Paul Heney, "2021 Global R&D Funding Forecast released," R&D World, February 22, 2021, https://www.rdworldonline.com/2021-global-rd-funding-forecast-released/.

151 "The United States Invests More in Applied and Basic Research than Any Other Country but Invests Less in Experimental Development than China," National Science Foundation, December 3, 2019, https://www.nsf.gov/statistics/2020/nsf20304/.

pioneering new technologies.[152] In international patent filings, China displaced the U.S. as the top user of the Patent Cooperation Treaty (PCT) in 2019, when it filed 22% of PCT patents, compared to 0.6% in 2000.[153] Meanwhile, the U.S. share fell from 42% to 22% during the same period. And in 2016, China overtook the U.S. as the top producer of scientific publications, now accounting for over 20% of science research output worldwide.[154] 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."[155]

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.[156] Moreover, the continued outsourcing of manufacturing and engineering poses a long-term threat to American technological prowess.[157] As described by former Intel CEO and Silicon Valley legend Andy Grove, "Without scaling, we don't just

152 Martin Wolf, "China is Wrong to Think the US Faces Inevitable Decline"; Ding Yi, "China Home to Six of the World's Top 10 Unicorns, Hurun Report Says," Caixin, August 5, 2020, https://www.caixinglobal.com/2020-08-05/china-home-to-six-of-the-worlds-top-10-unicorns-hurun-report-says-101589010.html.

153 The U.S. leads China by a large margin in triadic patents, which are recognized as the gold standard of patents as they are filed jointly with the Japan Patent Office, the United States Patent and Trademark Office, and the European Patent Office. However, China's share of triadic patents has grown at an increasing rate since 2015, and it also leads in patents registered with the Patent Cooperation Treaty (another important venue for international patents). See "Are Patents Indicative of Chinese Innovation?" China Power, updated August 26, 2020, https://chinapower.csis.org/patents/; "China Becomes Top Filer of International Patents in 2019 Amid Robust Growth for WIPO's IP Services, Treaties and Finances," World Intellectual Property Organization, April 7, 2020, https://www.wipo.int/pressroom/en/ articles/2020/article_0005.html; "Information Note: The Patent Cooperation Treaty (PCT) in 2000," World Intellectual Property Organization, February 13, 2001, https://www.wipo.int/export/sites/www/pct/en/activity/pct_2000.pdf.

154 Joy Zhang, "To Keep Nationalism in Check, Nurture Science Solidarity," Nature, March 2, 2021, https://www.nature.com/articles/d41586-021-00458-5; "The Perils of Complacency: America at a Tipping Point in Science & Engineering," American Academy of Arts & Sciences; Jeff Tollefson, "China Declared World's Largest Producer of Scientific Articles," Nature, January 18, 2018, https://www.nature.com/articles/d41586-018-00927-4.

155 Tarun Chhabra, William Hannas, Dewey Murdick, and Anna Puglisi, "Open-Source Intelligence for S&T Analysis," CSET, September 2020, https://cset.georgetown.edu/publication/open-source-intelligence-for-st-analysis/.

156 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/.

157 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.

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

158 Andy Grove, "How America Can Create Jobs," Bloomberg, July 1, 2010, https://www.bloomberg.com/news/articles/2010-07-01/andy-grove-how-america-can-create-jobs.

159 "The American Jobs Plan," White House, March 31, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/.

160 The Bipartisan Infrastructure Framework includes an initial investment of $550 billion and a total cost of $1.2 trillion over eight years. The Framework invests half of the resources initially proposed in the American Jobs Plan and largely excludes funding in core S&T areas, such as clean energy, tech R&D, and supply chain resiliency. See Jacob Pramuk, "House passes $1 trillion bipartisan infrastructure bill that includes transport, broadband, and utility funding, sends it to Biden," CNBC, November 5, 2021, https://www.cnbc.com/2021/11/05/house-passes-bipartisan-infrastructure-bill-sends-it-to-biden.html; "UPDATED FACT SHEET: Bipartisan Infrastructure Investment and Jobs Act," White House, August 2, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/02/updated-fact-sheet-bipartisan-infrastructure-investment-and-jobs-act/.

161 Tarun Chhabra, William Hannas, Dewey Murdick, and Anna Puglisi, "Open-Source Intelligence for S&T Analysis"; "(Authorized to issue) Communiqué of the Fifth Plenary Session of the 19th Central Committee of the Communist Party of China," Xinhua, October 29, 2020, http://www.xinhuanet.com/politics/2020-10/29/c_1126674147.htm.

emerging technologies.[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."[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.[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.[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

162 Examples include "Made in China 2025," the 2017 "New Generation Artificial Intelligence Development Plan," as well as the recently issued "Guiding Opinions on Accelerating the Application and Industrial Development of Blockchain Technology," which aims to position China as a leader in blockchain technology and standards by 2025. See Ryan Fedasiuk, Jennifer Melot, and Ben Murphy, "Harnessed Lightning: How the Chinese Military is Adopting Artificial Intelligence"; "Interpretation of Guiding Opinions on Accelerating the Application and Industrial Development of Blockchain Technology," Ministry of Industry and Information Technology, June 8, 2021, https://www.miit.gov.cn/zwgk/zcjd/art/2021/art_30c7489e3b3447318188d074f9f81044.html.

163 While Beijing's recent crackdown on tech companies has the potential to slow this timeline, the underlying structural reality of China's increased technological might offers a powerful counterweight. Rui Ma, "The China tech bubble is bursting. That's not a bad thing for investors," Rest of World, August 23, 2021, https://restofworld.org/2021/is-china-tech-still-investable/; Jing Yang, Keith Zhai, and Quentin Webb, "China's Corporate Crackdown Is Just Getting Started. Signs Point to More Tumult Ahead," Wall Street Journal, August 5, 2021, https://www.wsj.com/articles/china-corporate-crackdown-tech-markets-investors-11628182971; Matt Sheehan, "Forecast 2025: China Adjusts Course," MacroPolo, October 26, 2020, https://macropolo.org/wp-content/uploads/2020/10/china2025-final.pdf.

164 William Pesek, "China's big tech plan has echoes of Japan," Asia Times, March 20, 2021, https://asiatimes.com/2021/03/chinas-big-tech-plan-has-echoes-of-japan/.

165 GDP here is measured by purchasing power parity. See "Gross domestic spending on R&D (indicator)," OECD, accessed November 2021, https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm; "White Paper on Science and Technology 2006: Challenges for Building a Future Society," Japanese Ministry of Education, Culture, Sports, Science and Technology, 2006, https://www.mext.go.jp/en/publication/whitepaper/title03/detail03/1372834.htm.

(10% of U.S. VC spending at the time, measured by 2020 dollars).[166] 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.

166 Masaki Kuroki, Mark P. Rice, and Pier A. Abetti, "Emerging Trends in the Japanese Venture Capital Industry," The Journal of Private Equity, 2000, http://www.jstor.org/stable/43503251; Andrew Pollack, "Japan Faces the Unthinkable: A Shortage of Engineers," New York Times, January 2, 1994, https://www.nytimes.com/1994/01/02/business/japan-faces-the-unthinkable-a-shortage-of-engineers.html/; Herbert Ooghe, Ann Bekaert, and Peter Van Den Bossche, "Venture Capital in the U.S.A., Europe and Japan," Management International Review, 1989, http://www.jstor.org/stable/40227913.

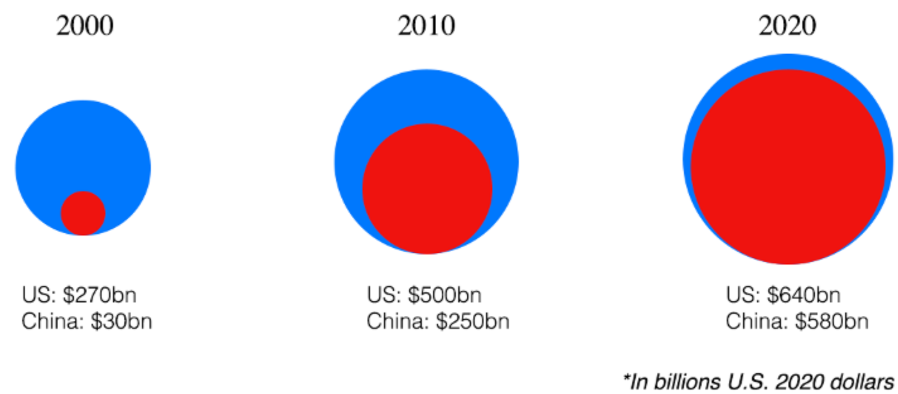
167 Daniel Slotta, "Value of new funds of venture capital companies in China from 2009 to 2020," Statista, February 17, 2021, https://www.statista.com/statistics/235339/fund-portfolio-of-venture-capital-companies-in-china/#:~:text=In%202020%2C%20the%20value%20of,of%20global%20venture%20capital%20investments.; Sophie Zinser, "The Global Reach of China's Venture Capital," January 21, 2021, https://thediplomat.com/2021/01/the-global-reach-of-chinas-venture-capital/; Rebecca Fannin, "China Rises to 38% of Global Venture Spending in 2018, Nears US Levels," Forbes, January 14, 2019, https://www.forbes.com/sites/rebeccafannin/2019/01/14/china-rises-to-38-of-global-venture-spending-in-2018-nears-us-levels/?sh=5061d6b65a5c.

168 Lee Branstetter and Yoshiaki Nakamura, "Is Japan's Innovative Capacity in Decline?" NBER Working Paper Series, No. 9438, January 2003, https://www.nber.org/papers/w9438; Jonathan Weeks, "Galapagos Syndrome and the Birth of Tap and Go Experiences," Mitsue, January 19, 2018, https://www.mitsue.co.jp/english/global_ux/blog/201801/19_1400.html.

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."[169]

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

Source: AMACAD "The Perils of Complacency"; OECD Main Science and Technology Indicators



169 "The Perils of Complacency: America at a Tipping Point in Science & Engineering," American Academy of Arts & Sciences.

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