AVOIDING GREAT POWER WAR PROJECT

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

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HARVARD Kennedy School
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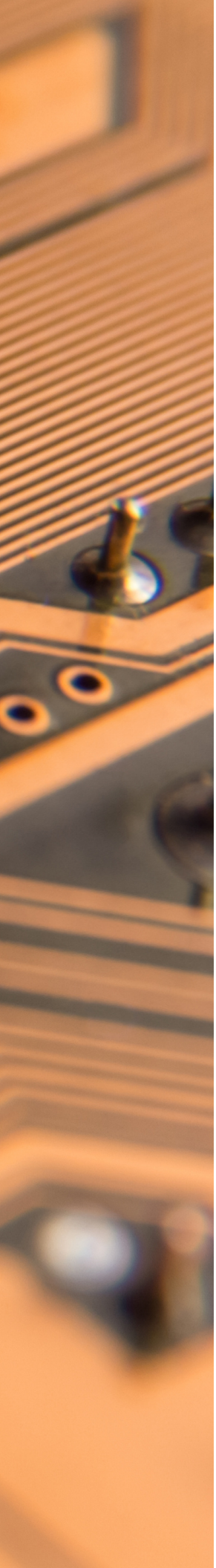
MADE IN CHINA



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 mar-ketplace: 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.[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 inno-vate.[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 rewall, the logic went. So rampant were the issues of copycat so ware and shanzhai[4] electronics in China that Microso famously abandoned its e orts to stem pirated copies of Windows.

Today, China's rapid rise to challenge U.S. dominance of technology's commanding heights has captured America's attention. e rivalry in tech nology 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, pro ducing 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: arti cial 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 (• Ž) 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 eld, and competition for tech dominance will grow unprecedentedly erce.”[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 identi es 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.

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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, nancial market tests, research publications, patents, and results in international competitions.

Consumers' choices of AI products in markets speak for themselves. In speech technology, Chinese rms are beating American rms in every language, including English. e 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 nancial technology (ntech), 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] is spending generates a treasure trove of granular data about individual consumer behavior that can be used to develop other ntech 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 re ect these realities. Six years ago, two of the world's twenty most valuable internet companies were Chinese; today, seven are. Google, Amazon, Facebook, Microso , Baidu, Alibaba, and Tencent—the "Seven Giants of the AI age"—are split on either side of the Paci c. Of every ten venture capital dollars invested in AI in 2018, ve went to Chinese startups; four to American rms.[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 new reality is that China is laying the intellectual groundwork for a generational advantage in AI. e Air Force's former Chief So ware O cer, 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 2018.[24] AI's hottest sub eld—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] In contrast, the number of domestic-born AI PhDs in the U.S. has not increased since 1990.[30]

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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.