

The background features a dark blue field with various geometric shapes in red and blue. At the top, there are two red semi-circles, a white line-art globe with nodes, and a blue square with a white square inside. To the right, there are three red dots and a white vertical line. Below the text, there are several icons: a hand holding a gear, a gear with a brain-like structure, and a white circle. The overall design is modern and technical.

SPECIAL COMPETITIVE STUDIES PROJECT

PLATFORMS

Interim Panel Report

November 2022

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The Platforms Panel Interim Panel Report (IPR) is the fourth of six interim reports from the overall work that the Special Competitive Studies Project (SCSP) has conducted over the past year and that was summarized in our [Mid-Decade Challenges to National Competitiveness](#) report published on September 12, 2022. This report benefited greatly from insights and expertise by a number of individuals to whom we are deeply grateful. It aims to reflect many, though not all, of those insights. It was prepared by the SCSP staff and, as such, it is not a consensus document of all the experts who assisted.

PLATFORMS PANEL INTERIM PANEL REPORT

Harnessing the New Geometry of Innovation

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Executive Summary

Resolving the paradox of a nation with overwhelming technology advantages suffering from relative technological vulnerabilities is one of the fundamental tasks before the United States today. The technological future is playing out and the United States is not guaranteed to lead it. Already, the United States has found itself in strategically precarious technology positions in key areas including fifth-generation cellular networks technology (5G), artificial intelligence (AI), and microelectronics. Despite overwhelming technological advantages including leading universities, the most innovative startups, powerful global technology companies with platforms used around the world, and deep capital markets, the United States is not the world's leader in many important tech areas (as explained below), and it is in a close contest with China in many others.

The technological revolutions in artificial intelligence, computing power, next generation networks, biotechnology, new forms of energy production and storage, and at the intersection of multiple technologies such as advanced manufacturing is playing out in a geopolitical and ideological context that raises the stakes to the highest order. At the most basic level, technological advantage presents a nation with opportunities to generate economic power and military capabilities, and it creates the ability to shape the global order to comport with an ideological vision. China recognizes this dynamic and is moving to secure positional advantages and use its technological power to exert its influence abroad. The United States has been slow to wake up to this competition.

The nations that harness their innovation ecosystems in line with their strategic national needs will be best positioned to win. The United States can leverage its underlying strengths in new ways to generate specific advantages in critical technology areas. To do so, the United States should combine (1) a national public-private process, (2) a long-term organization to house it, and (3) specific technology action plans to secure leadership in a range of additional technologies.

Part I: The Stakes, Gaps, & Systems that Require a New Innovation Model

The Stakes: The Future of Technology, Democracy, and Geopolitics

Emerging technologies are shaping state power, prosperity, and principles. Whether a nation maintains a technological edge will determine the tools of statecraft at its disposal, its ability to provide for its people, and its ability to advance its interests and values on the global stage. Such a reality is already emerging as the People’s Republic of China (PRC) pursues a series of seven “Tech Spheres of Influence” across the globe that augment its power. Left unchecked, those Tech Spheres of Influence will allow illiberal states to project power and ultimately reshape the world toward authoritarianism.

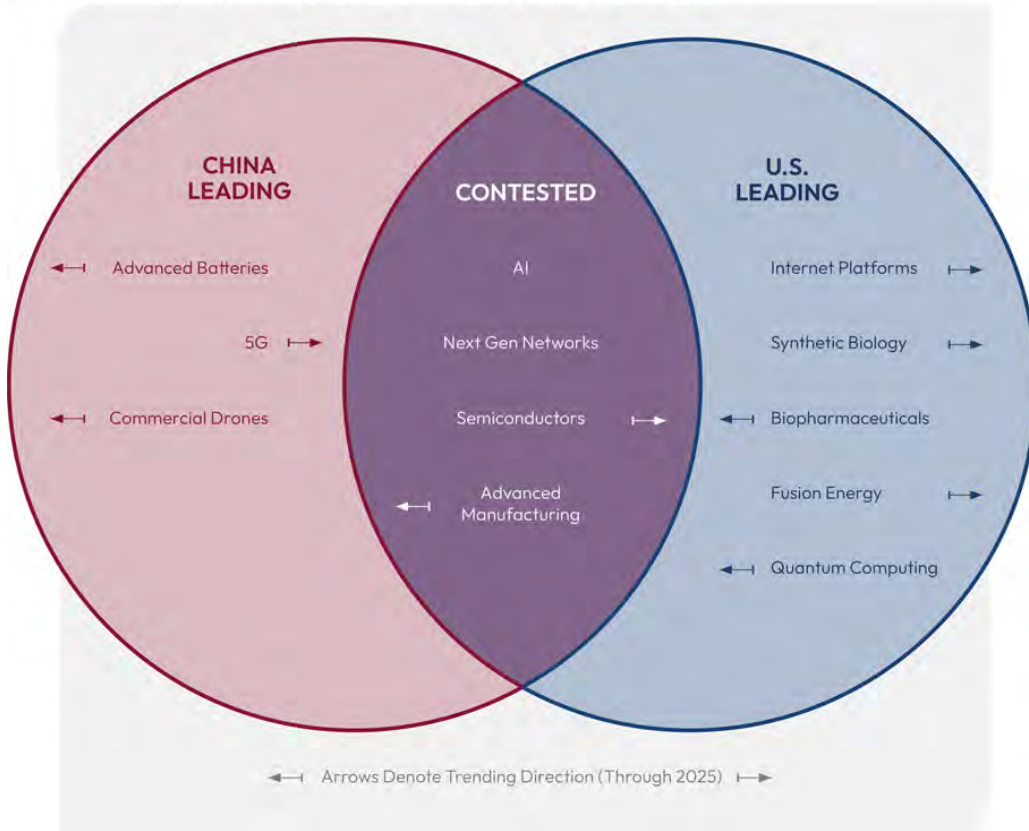


The Gaps: Assessing the U.S.-China Tech Competition

A range of critical technologies across the digital, physical, and biotechnical domains will shape the future. The United States leads today in internet platforms, synthetic biology, biopharmaceuticals, quantum computing, and fusion energy while the PRC leads in 5G network components, advanced batteries, and commercial drones. Other technologies are contested, including AI, next generation networks, semiconductors, and advanced manufacturing. In many cases, trend lines point to tenuous leads lost and the seeds of new gaps being sown.

Leadership in Key Technologies is Increasingly Contested

This graphic summarizes SCSP staff’s assessment of the current state of U.S. - China competition in specific technology areas, as well as the direction in which leadership in those technologies is trending through 2025. For our full analysis including methodology and confidence judgments, please see Appendix A of this report.



The Systems: Comparing U.S. and PRC Innovation Ecosystems

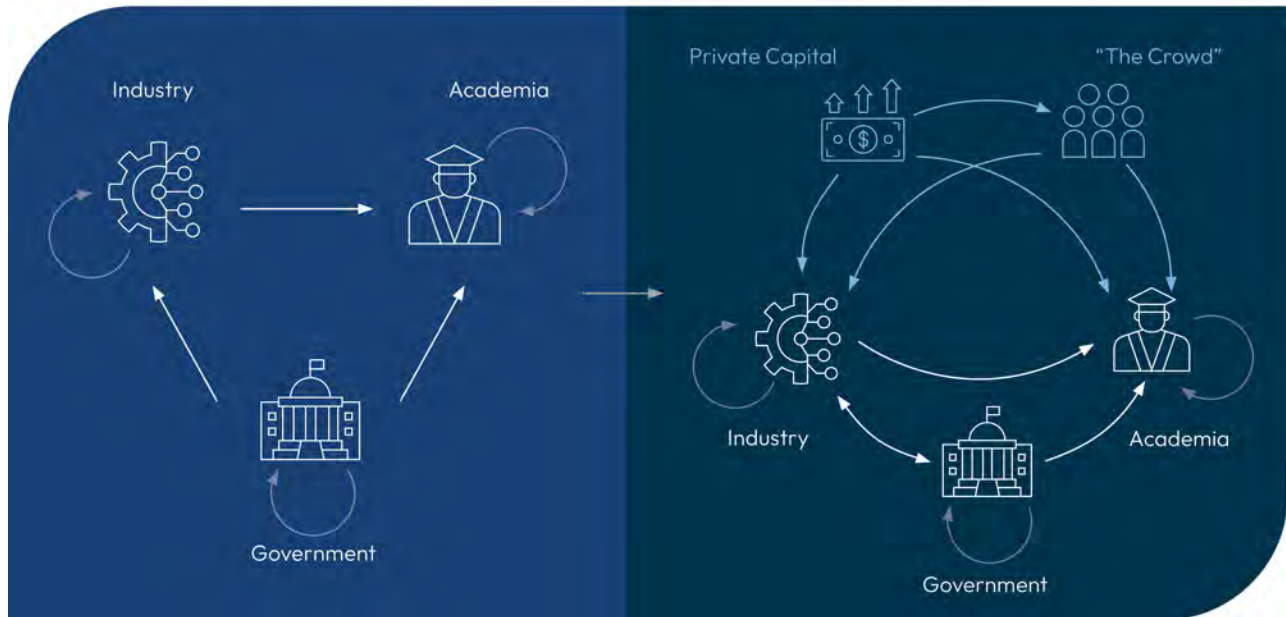
Dominant technology positions arise from competing innovation systems. The differences between those systems – and each nation’s ability to leverage its innovation geometry – will determine the outcome of the multi-decade competition. The latent power of the U.S. technology ecosystem is not currently being harnessed for national purposes. To regain and create new forms of leadership the United States must harness a new geometry of innovation that accounts

for the declining role of the federal government in fostering innovation, and the rise of venture capital, the web-enabled “crowd,” and the overall power of the private sector to shape tech investments and applications. The Cold War triangle of innovation has taken on a new shape. The United States must adapt.

New Geometry of Innovation

The Vannevar Bush Triangle of Innovation

The New Innovation Landscape

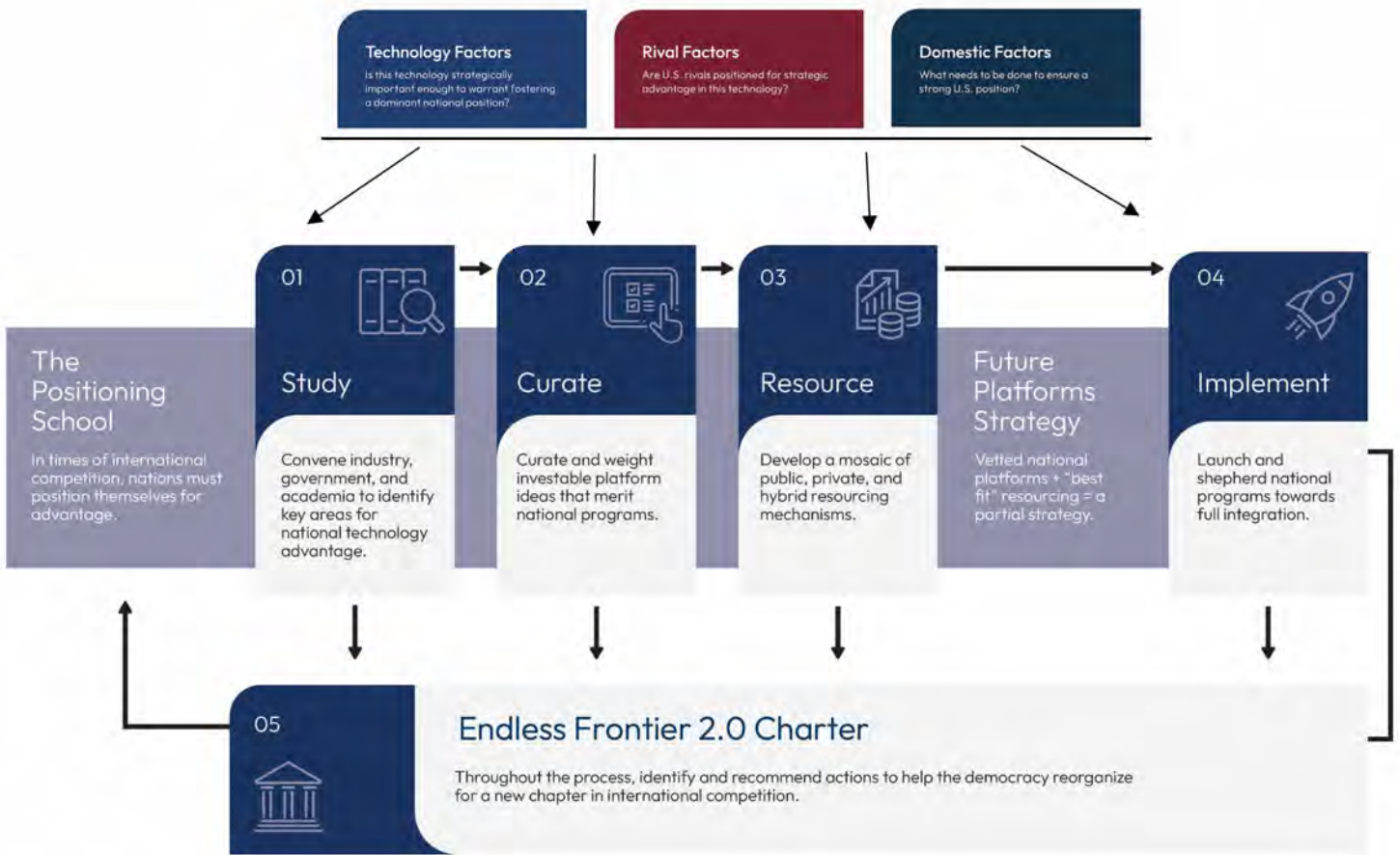


Part II: A Complete Competition Model for America

The Process: How Would the Public-Private Model Actually Work?

Positioning the nation for advantage requires a process that harnesses America’s new geometry of innovation by incorporating government stewardship and incentives with private sector insight and resources. Private sector strategy advisors, horizon scanners, technology thought leaders across and within sectors, and investors can partner with the government in a sustainable and voluntary national technology strategy process. Informed by a framework for evaluating the strategic significance of any given technology, these actors can support an iterative process of studying the rival ecosystem and technology horizons, curating Technology Action Plans (TAPs) for key technologies, creatively matching a mosaic of resources to those plans, and overseeing their implementation. When combined with a techno-industrial strategy that builds a strong foundation of economic inputs and policies, the end result is a full competition model for the nation.

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The Place: What are the Organizational Options for Hosting the Public-Private Model?

Based on a rubric of elements for an ideal entity to conduct the national technology strategy process and assessments of four potential options, creating a White House-based Technology Competitiveness Council (TCC) paired with an Office of Global Competition Analysis (OCA) would best enhance American competitiveness. The OCA would serve as an analytic support function to a TCC-led policy process. That TCC/OCA pairing might be further enhanced by standing up a federally chartered, but government adjacent, space for industry information sharing and investment coordination, a U.S. Advanced Technology Forum (USATF).

The Plans: What are the Right Elements of an Action Plan for U.S. Advantage in a Specific Technology?

The outcomes of a national technology strategy process are Technology Action Plans that move the U.S. innovation ecosystem towards achieving a position of advantage in a given technology. They incorporate long-standing goals of encouraging breakthroughs with a wider recognition that breakthroughs must be translated into practical applications at scale to create positional advantage. TAPs map out whole of nation efforts to unleash U.S. advantage by combining a bold technology goal with policy, market, infrastructure, and talent levers. **Fusion energy** – a novel form of energy generation approaching commercial relevance – is an example by which a TAP today can lay the groundwork for global U.S. fusion leadership by 2030.

PART I: The Stakes, Gaps, & Systems That Require a New Innovation Model

The Stakes: The Future of Technology, Democracy, and Geopolitics

The United States is awakening to the growing international technology competition that will define the coming decades. The United States and the PRC are competing to shape the future. Emerging technologies are at the heart of this contest. What's at stake is more than bragging rights. Technology leadership is a form of power that shapes policy in the real world.

Advanced technologies are already reshaping U.S. national security and national competitiveness. AI systems, new sensor technologies, and human-machine teaming can expand military awareness, improve logistics, and bring more force to a fight.¹ In a world with more assertive authoritarian regimes, new paradigms in advanced manufacturing will help decide if the United States can foster the necessary industrial base to serve as the 21st Century “arsenal of democracy.”²

¹ [The Future of Conflict and the New Requirements of Defense](#), Special Competitive Studies Project at 10-14 (2022).

² See [The Future of Conflict and the New Requirements of Defense](#), Special Competitive Studies Project at 8 (2022); Thomas Mahnken, [Could America Win a New World War?](#), Foreign Affairs (2022). On the historical arsenal of democracy, see generally Arthur Herman, [Freedom's Forge](#), Random House (2013).



New technologies offer a potential future of expanded economic prosperity, with new products, services, and good paying jobs. An emerging bioeconomy holds the promise of trillions of dollars in original economic opportunity.³ New forms of energy generation can provide clean power that reorients geopolitical dependencies.⁴ Advanced manufacturing can elevate American communities and reduce supply chain vulnerabilities.⁵ Such developments will make the American economy more resilient and create new opportunities.

The principles that guide and the values imbued in these technologies will matter tremendously. Will these technologies lean toward respect for human rights and individual autonomy or be mechanisms to surveil, coerce, and suppress? AI models can drive both quicker medicinal discovery and autonomous disinformation campaigns.⁶ Biotechnology will open economic doors, but quickly implicates issues of privacy, targeting, and ownership rights. New energy could be wielded as either a geopolitical carrot or stick.

The regime type that leads in these emerging technologies matters. Leaders will shape norms and standards. They will amass early economic gains for their nations, which can be reinvested to further drive technological advantage. They will employ technologies as tools of national power with real consequences in the world, affecting countries' policy choices and individuals' lives.

³ Michael Chui, et al., [The Bio Revolution: Innovations Transforming Economies, Societies, and Our Lives](#), McKinsey Global Institute (2020); [Remarks by NSC Senior Director for Technology and National Security Tarun Chhabra at the Brookings Institution](#), Brookings Institution at 19:19 (2022).

⁴ [Fact Sheet: Developing a Bold Vision for Commercial Fusion Energy](#), The White House (2022).

⁵ [National Strategy for Advanced Manufacturing, Subcommittee on Advanced Manufacturing](#), National Science and Technology Council (2022); Nelson Schwartz, [Supply Chain Woes Prompt a New Push to Revive U.S. Factories](#), New York Times (2022).

⁶ See [Why Artificial Intelligence Could Speed Drug Discovery](#), Morgan Stanley (2022); Bradley Honigberg, [The Existential Threat of AI-Enhanced Disinformation Operations](#), Just Security (2022).

That impact is not speculative. It is already unfolding through a series of “Tech Spheres of Influence” that the PRC is pursuing to impact the world. As the PRC has developed greater advanced technological capacity in a range of sectors, those abilities have been deployed in service of a more assertive foreign policy. That assertiveness impacts America’s security, economy, society, and those of friends and allies around the globe. While one might think China’s increasing coercive acts⁷ would push many actors away, the reality is more muddled. As long as the PRC offers competitive, affordable technology, nations and even smaller communities may seek a foot on both sides despite security- or values-based reservations.⁸ If the United States fails to compete in key technology battlegrounds, it will lose its ability to shape global rules and norms that guide the application of these technologies. Absent action, those Tech Spheres of Influence defined by authoritarian values will grow.

Tech Spheres of Influence today go beyond the regional or single domain-specific spheres of influence accrued by great powers past.⁹ The seven identified spheres, described in turn below, are far-reaching and fluid in how they relate to each other. They do not neatly overlay on a map, nor even align to geography. Some are emerging *de facto*. Others are resulting from concerted PRC strategy and action. No one sphere alone is foundationally changing the world. Nonetheless, the United States must remain alert to the fact that *together* they pose a serious challenge to the democratic world in the abilities they provide the PRC to influence governments and international bodies, coerce private companies competing with PRC-based firms, and impact the rights, liberties, and daily lives of individuals around the globe.

⁷ See Paul Karp, [Morrison Speaks Out Against China’s “Economic Coercion” at Davos](#), The Guardian (2022); Elisabeth Braw, [China Takes Lithuania as an Economic Hostage](#), Wall Street Journal (2022); Maya Wang, [China’s Algorithms of Repression](#), Human Rights Watch (2019); Chris Buckley & Paul Mozur, [How China Uses High-Tech Surveillance to Subdue Minorities](#), New York Times (2019).

⁸ Shannon Van Sant, [MEPs Cry Foul as Strasbourg Airport Buys Chinese Scanners](#), Politico (2022); Steven Feldstein, [The Global Expansion of AI Surveillance](#), Carnegie Endowment for International Peace (2019).

⁹ See Valentin Weber, [Making Sense of Technological Spheres of Influence](#), LSE Ideas (2020); Matthias Schulze & Daniel Voelsen, [Digital Spheres of Influence](#) in Strategic Rivalry Between United States and China Causes, Trajectories, and Implications for Europe at 30-34 (2020).



First, states are jockeying over access to and control over the *critical minerals and rare earth elements (REEs)* that serve as critical inputs for the manufacturing of most technologies. Currently, China is a global leader in all three main segments of the rare earth element supply chain: mining, refinement, and “component manufacturing,” including for permanent magnets.¹⁰

Second, the modern world is connected by *global communications systems* – from wireless networks to satellites and undersea cables – that comprise the backbone of the digital world, and which China seeks to control. The United States has struggled to respond to China’s international reach in wireless infrastructure. The PRC’s Huawei and ZTE claim almost a 40 percent share of the global telecommunications equipment manufacturing market, while no U.S. firm builds integrated 5G telecommunications networks abroad.¹¹ This contest is expanding to undersea cables and low earth orbit satellites in a growing race to own, build, and service the networks that connect the globe.¹²

¹⁰ [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project at 19-22 (2022); Brandon S. Tracy, [An Overview of Rare Earth Elements and Related Issues for Congress](#), Congressional Research Service at i (2020).

¹¹ Graham Allison & Eric Schmidt, [China’s 5G Soars Over America’s](#), Wall Street Journal (2022); John McCormick, et al., [Huawei, Ericsson or Nokia? Apple or Samsung? U.S. or China? Who’s Winning the 5G Races](#), Wall Street Journal (2021).

¹² On undersea cables, see Matthew Goodman & Matthew Wayland, [Securing Asia’s Subsea Network: U.S. Interests and Strategic Options](#), Center for Strategic and International Studies (2022); Justin Sherman, [Cyber Defense Across the Ocean Floor: The Geopolitics of Submarine Cable Security](#), Atlantic Council (2021). On commercial satellites, see Ashlee Vance, [Elon Musk’s Starlink Is at the Forefront of a Corporatized Space War in Ukraine](#), Bloomberg (2022);

Third, China is offering real options – eventually looking to lead – in emerging sectors like *biotechnology*, *financial technology (fintech)*, and *blockchain* that will also serve as conduits for influence abroad. Each provides China domestic economic opportunities – a portion of an estimated \$4–30 trillion bioeconomy,¹³ systems for efficient cashless transactions,¹⁴ and low-cost bets on blockchain-based digital infrastructure.¹⁵ But each also offers levers for influence abroad and serves the PRC’s intelligence, foreign policy, and national security interests. Synthetic biology and biopharmaceuticals can support food and health diplomacy.¹⁶ The digital renminbi (e-CNY) might enable sanctions avoidance.¹⁷ Each sector will also feed new data into the PRC’s surveillance state.¹⁸

Fourth, China recognizes that shaping international *technological standards and norms* is a structural path to ensuring future technological and economic advantage.¹⁹ China possesses and has enshrined in written strategy²⁰ an “explicit goal of becoming ‘a standards-issuing country’” to drive “its global success in these technocratic bodies and in the technologies they yield.”²¹ The PRC has inundated international technology standard-making bodies with representatives and leadership candidates who uniquely vote in a bloc for PRC-backed standards.²² Standards leadership will allow the PRC to shape which companies are most competitive, whose regulatory

Julia Siegel, [Commercial Satellites Are on the Front Lines of War Today. Here’s What This Means for the Future of Warfare](#), Atlantic Council (2022).

¹³ Michael Chui, et al., [The Bio Revolution: Innovations Transforming Economies, Societies, and Our Lives](#), McKinsey Global Institute (2020); [Remarks by NSC Senior Director for Technology and National Security Tarun Chhabra at the Brookings Institution](#), Brookings Institution at 19:19 (2022).

¹⁴ See [Digital Currencies: The US, China, And The World At A Crossroads](#), Hoover Institution at 23–43 (2022).

¹⁵ Kristen Busch, [Blockchain: Novel Provenance Applications](#), Congressional Research Service (2022); Mikk Ruad, [Knowledge Base: Blockchain-Based Service Network \(BSN, 区块链服务网络\)](#), Stanford University DigiChina (2021).

¹⁶ See María Eugenia Brizuela de Ávila, et al., [US-China Vaccine Diplomacy: Lessons from Latin America and the Caribbean](#), Atlantic Council (2021); Amy Beaudreault, [China’s Growing Power for a Food Secure World](#), Center for Strategic and International Studies (2020).

¹⁷ See Elena Fabrichnaya, et al., [Russia Plans to Use Digital Rouble in Settlements with China, Says Lawmaker](#), Reuters (2022); Dan de Luce, [U.K. Spy Chief Warns China’s Use of Technology Threatens Global Security](#), NBC News (2022); [The Digital Yuan Offers China a Way to Dodge the Dollar](#), The Economist (2022). See also [Digital Currencies: The US, China, And The World At A Crossroads](#), Hoover Institution at 94–99 (2022) (discussing sanctions and other national security implications of the e-CNY).

¹⁸ See [China’s Collection of Genomic and Other Healthcare Data from America: Risks to Privacy and U.S. Economic and National Security](#), U.S. National Counterintelligence and Security Center (2021).

¹⁹ Daniel Russel & Blake Berger, [Stacking the Deck: China’s Influence in International Technology Standards Setting](#), Asia Society Policy Institute at 12–13, 19–20 (2021). See also John Chen, et al., [China’s Internet of Things](#), SOSi at 3 (2018).

²⁰ See Matt Sheehan, et al., [Three Takeaways From China’s New Standards Strategy](#), Carnegie Endowment for International Peace (2021); Emily de La Bruyère & Nathan Picarsic, [China’s Next Plan to Dominate International Tech Standards](#), TechCrunch (2020).

²¹ Lindsay Gorman, [The U.S. Needs to Get in the Standards Game—With Like-Minded Democracies](#), Lawfare (2020).

²² Valentina Pop, et al., [From Light Bulbs to 5G, China Battles West for Control of Vital Technology Standards](#), Wall Street Journal (2021); Sujai Shivakumar, [Securing Global Standards for Innovation and Growth](#), Center for Strategic and International Studies (2022); Daniel Russel & Blake Berger, [Stacking the Deck: China’s Influence in International Technology Standards Setting](#), Asia Society Policy Institute at 26 (2021).

environments are most favorable, and what conceptions of human rights are built into the technologies of today and tomorrow.

Fifth, China is undertaking an international campaign to surveil and manipulate via *data collection, influencing social media, and exporting surveillance tools*. PRC state-owned enterprises and private technology companies capture large amounts of data from across the globe.²³ For the PRC, data is both a key economic and national security ingredient.²⁴ The PRC is helping next generation surveillance “go global” via its particular form of “smart city” packages, imbued with surveillance technologies.²⁵ The Chinese Communist Party (CCP) also collects vast amounts of data on foreign persons through a variety of private services or collaborations.²⁶ These mechanisms are used to track and suppress dissidents, as well as gain intelligence on individuals for future use.²⁷ Furthermore, the PRC is increasingly using its social media platforms to amplify its preferred narratives and repress dissenting views.²⁸ Simultaneously, PRC-aligned actors are becoming more active on U.S.-based social media platforms to muddy the waters on issues of importance to the state, such as human rights violations in Hong Kong and Xinjiang.²⁹

Sixth, the PRC is a new actor in the traditional influence sphere of *foreign military sales and equipment*. While the United States and China remain the global leaders in arms exports, China is now solidly on the board as the fourth largest global arms exporter.³⁰ As the PRC exports more software-based – and even AI-enabled – defense technologies with a persistent and complex

²³ Lindsay Gorman, [China’s Data Ambitions: Strategy, Emerging Technologies, and Implications for Democracies](#), National Bureau of Asian Research (2021).

²⁴ The PRC has come to view data as a factor of production. See [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project at 67-71 (2022). On the PRC’s use of data for domestic social control, see David Barboza, [Josh Chin & Liza Lin on How China Developed its ‘All-Seeing’ Surveillance State](#), Wire China (2022); Samantha Hoffman, [Social Credit](#), Australian Strategic Policy Institute (2018).

²⁵ Steven Feldstein, et al., [The Global Struggle Over AI Surveillance](#), National Endowment for Democracy (2022). For a specific case study of an illiberal government wielding an exported Chinese-based surveillance service, see the case of Venezuela. Press Release, [Treasury Sanctions CEIEC for Supporting the Illegitimate Maduro Regime’s Efforts to Undermine Venezuelan Democracy](#), U.S. Department of the Treasury (2020); E.O. 13808, [Imposing Additional Sanctions With Respect to the Situation in Venezuela](#) (2017).

²⁶ Jessica Dawson & Tarah Wheeler, [How to Tackle the Data Collection Behind China’s AI Ambitions](#), Brookings Institute (2022); [China’s Collection of Genomic and Other Healthcare Data from America: Risks to Privacy and U.S. Economic and National Security](#), U.S. National Counterintelligence and Security Center (2021); [2021 Report to Congress](#), U.S.-China Economic and Security Review Commission (2021); Samantha Hoffman, [The U.S.-China Data Fight is Only Getting Started](#); Foreign Policy (2021).

²⁷ See Maya Wang, [China’s Techno-Authoritarianism Has Gone Global](#), Human Rights Watch (2021); Miles Kenyon, [WeChat Surveillance Explained](#), Citizen Lab (2020).

²⁸ Sarah Cook, [Special Report 2020: Beijing’s Global Megaphone](#), Freedom House (2020); Yaqiu Wang, [How China’s Censorship Machine Crosses Borders – and Into Western Politics](#), Human Rights Watch (2019).

²⁹ Muye Xiao, et al., [Buying Influence: How China Manipulates Facebook and Twitter](#), New York Times (2021).

³⁰ [International Arms Transfers](#), Stockholm International Peace Research Institute (2022).³⁰ [International Arms Transfers](#), Stockholm International Peace Research Institute (2022). Additionally, increased international isolation of Russia since its February 2022 aggression against Ukraine has opened new opportunities for the PRC to amass global market share in the sale of low-end weapons. Vasabjit Banerjee & Benjamin Tkach, [The Coming Chinese Weapons Boom](#), Foreign Affairs (2022).

logistical tail, it could turn one-time buyers into returning clients.³¹ Critically, unlike Russia, the PRC's broader technological capabilities enable it to offer a wide range of advanced goods and services that it might package, and fund, alongside specific defense technologies. Furthermore, in these arrangements the PRC feels no compunction to abide by the human rights standards that are core to U.S. foreign military sales.³²

Seventh and finally, the PRC is building and financing advanced *strategic infrastructures* around the world. Since 2011, China has surged forward as an exporter of high-speed rail technology.³³ This self-described “high-speed rail diplomacy” extends to the developing and developed world alike, including to the United States.³⁴ Similarly, the PRC's efforts and investments around international ports are well documented.³⁵ Beijing is deeply involved in not only refurbishing ports, but in merging physical and digital infrastructure in “smart ports” that provides economic efficiency but with security and surveillance vulnerabilities.³⁶

Ultimately, the PRC takes a holistic view of these Tech Spheres of Influence. The PRC's Belt and Road Initiative (BRI), and its digital program, the Digital Silk Road (DSR), work across many of the preceding seven spheres, allowing China to project and build its influence abroad in mutually reinforcing ways.³⁷ Thus, surveillance packages or diplomatic pressure to align standards and norms can accompany strategic infrastructure investments and talent exchange programs. The BRI/DSR framework provides the PRC a platform for bundling its technology exports and services, tying countries to Beijing with multiple knots. The result is a well-spun web that gives China multiple inroads to co-opt foreign governments, cajole foreign businesses, and coerce foreign persons at odds with the CCP's interests.

The Gaps: Assessing the U.S.-China Tech Competition

While a number of factors can feed the rise of Tech Spheres of Influence, one path is when the PRC offers a superior technology than that which the United States and its allies could provide.

³¹ Patrick Tucker, [SecDef: China is Exporting Killer Robots to the Mideast](#), Defense One (2019).

³² See Paul Kerr & Liana Rosen, [U.S. Arms Sales and Human Rights: Legislative Basis and Frequently Asked Questions](#), Congressional Research Service at 1-2 (2021); [Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2019](#), U.S. Department of Defense at 27-28 (2019) (discussing PRC arms sales).

³³ Michelle Kerr, [China's High-Speed Rail Diplomacy](#), U.S.-China Economic and Security Review Commission at 3-4 (2017).

³⁴ Michelle Kerr, [China's High-Speed Rail Diplomacy](#), U.S.-China Economic and Security Review Commission at 4, 11-18 (2017).

³⁵ See Leonie Kijewski, [Germany Reaches Compromise on China's Hamburg Port Investment, Reports Say](#), Politico (2022); Stu Woo & Daniel Michaels, [China Buys Friends With Ports and Roads. Now the U.S. Is Trying to Compete](#), Wall Street Journal (2021).

³⁶ See [China Merchants Port Group and Alibaba Join Forces for Smart Port](#), Maritime Executive (2020). In 2021 Huawei launched its “smart port solution” tool. [Huawei Launches the Smart Port Solution to Help Build World-Class Ports](#), PR News Wire (2021).

³⁷ Yu Ji & Jon Wallace, [What is China's Belt and Road Initiative \(BRI\)?](#), Chatham House (2021); [Assessing China's Digital Silk Road Initiative](#), Council on Foreign Relations (last accessed 2022).

Technology gaps, therefore, translate to national power not only on a hypothetical future battlefield, but on the ground today in countries around the globe. To ensure U.S. security and competitiveness, the United States cannot afford to let certain gaps emerge.

Closing existing gaps and preventing new ones requires seeking technological power. There is no guarantee that a nation will always be wise in its use of that power. One can only offer that being strong with dominant technology positions is better than being weak. The world continues to illustrate that in times of intense strife “the strong do what they will and the weak do what they must.”³⁸ Securing leading technology positions is a form of national power and thus, an abiding interest of nations who seek peace through strength.

As outlined in SCSP’s report *Mid-Decade Challenges to National Competitiveness*, six general purpose technology sectors will be essential sources of that technological power: AI, microelectronics and the next computing paradigms, networks, biotechnology, new forms of energy production and storage, and technologies like smart manufacturing at the convergence of those sectors.³⁹ Today, leadership in each of those sectors is uncertain.

Within these sectors, the United States currently maintains a tenuous lead in some technology areas: Internet platforms, synthetic biology, biopharmaceuticals, quantum computing, and fusion energy. In others, the PRC appears to have surged ahead, enjoying an advantage in 5G network components, advanced batteries, and commercial drones. Finally, there are key contested sectors too close to determine a clear frontrunner. For example, core areas of AI, next generation networks, semiconductors, and advanced manufacturing hang on a knife’s edge.⁴⁰

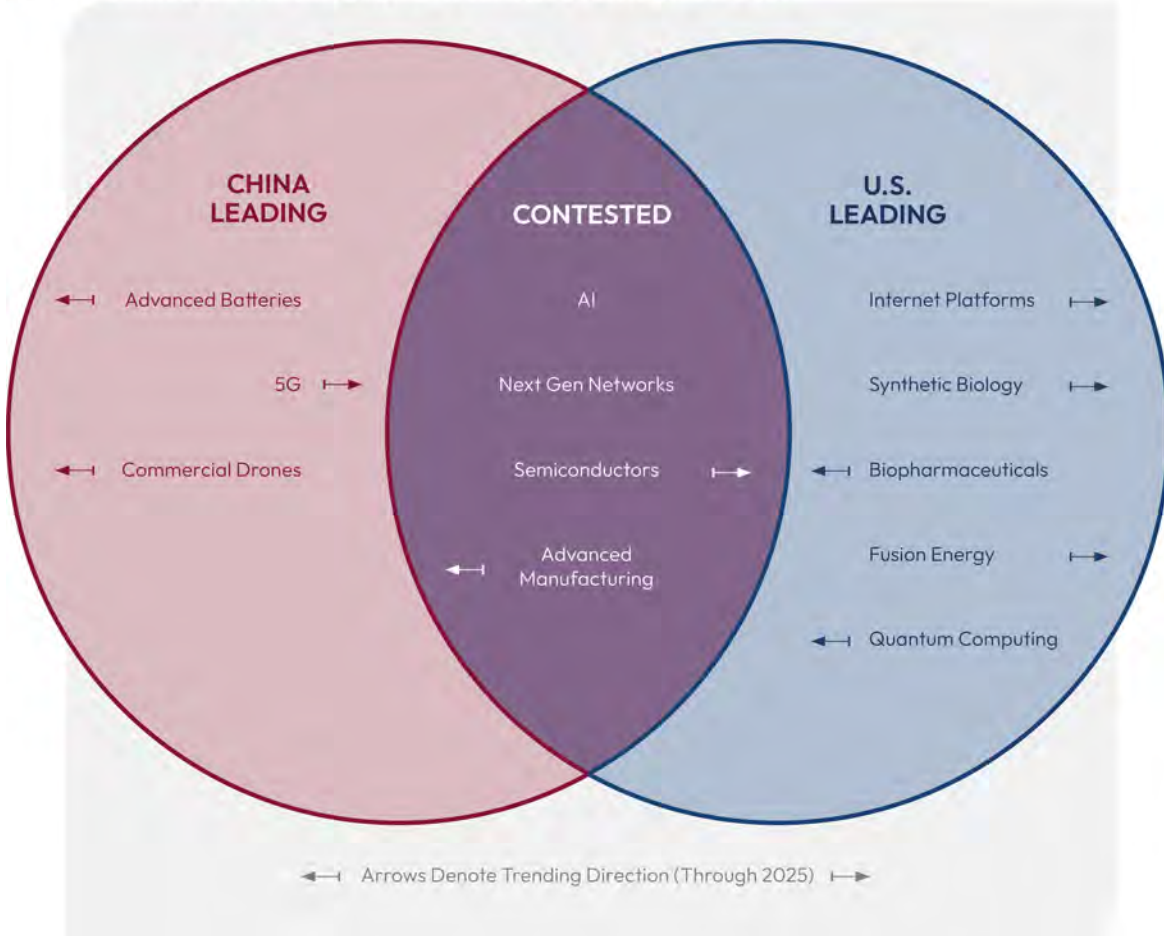
³⁸ Thucydides, [History of the Peloponnesian War](#), Penguin Classics at Book 5, Section 89 (1972).

³⁹ [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 170-181 (2022).

⁴⁰ These assessments were derived using the methodology described in Appendix A of this report. For more detailed analysis of each technology see Appendix B of this report. This analysis is also an example of the type of techno-economic analysis that can be generated using open sources. For more information, see [Intelligence in An Age of Data-Driven Competition](#), Special Competitive Studies Project (2022).

Leadership in Key Technologies is Increasingly Contested

This graphic summarizes SCSP staff’s assessment of the current state of U.S. - China competition in specific technology areas, as well as the direction in which leadership in those technologies is trending through 2025. For our full analysis including methodology and confidence judgments, please see Appendix A of this report.



Looking ahead, directional trajectories show a growing number of technologies – particularly in areas where the United States doesn’t enjoy a multi-decade unchallenged incumbency – that the PRC will increasingly contest. This exercise reveals that while the U.S. economy operates well in many respects, the American innovation ecosystem is wide open and not optimized for a serious international techno-economic competition that requires foresight and speed in technology development.

Caveats for Declaring Technology Gaps

Assessing and declaring strategic gaps in technology advantage is a hazardous exercise. On one hand, perceived gaps can be wrong. The Cold War bomber and missile “gaps” did not bear out.⁴¹ Inaccurate diagnoses can divert scarce resources from higher priority needs. Gaps can occur at different levels of analysis, carry different meanings, and be misperceived. Reasonable people may disagree about which gaps matter or what drivers and factors to use for the comparisons. Gaps can also be fleeting, and today’s assessments are poised to shift even more rapidly as technologies like AI supercharge scientific discovery and converge with other general-purpose technologies on the horizon. Further, comparative or net assessments are notoriously difficult to conduct in the Intelligence Community due to concerns that such an exercise could cross the line of collecting domestic intelligence.⁴²

We offer this analysis humbly and with caution. This list is neither an exhaustive nor comprehensive net assessment of the United States and the PRC across all technology sectors. Rather, it examines a smaller subset of technology areas within six key sectors as barometers of the competition.⁴³




⁴¹ See [50th Anniversary of the Missile Gap Controversy](#), John F. Kennedy Presidential Library and Museum (last accessed 2022); Gregory Pedlow & Donald Welzenbach, [The Central Intelligence Agency and Overhead Reconnaissance: The U2 and OXCART Programs, 1954-1974](#), U.S. Central Intelligence Agency (1992) (discussing the bomber and missile gaps).

⁴² A national techno-economic intelligence center could help address these concerns. See [Intelligence in an Age of Data-Driven Competition](#), Special Competitive Studies Project at 28-34 (2022).




⁴³ For each technology listed we provide a current assessment and a trend line. For both, we also provide a confidence interval in parentheses. Ranking from low to moderate to high, the confidence interval is a reflection of SCSP staff’s judgment based on available indicators or proxy indicators. See Appendix A of this report for a detailed discussion of the methodology behind this assessment.

Assessing the U.S.-China Technology Competition



Battleground	Technology	Current Assessment	Trend Line
 Software	Artificial Intelligence	Contested	Contested
	Internet Platforms	U.S.-Lead	Trending U.S.
 Biotechnology	Synthetic Biology	U.S.-Lead	Trending U.S.
	Biopharmaceuticals	U.S.-Lead	Contested
 Networks	5G	PRC-Lead	Contested
	Next Generation Networks	Contested	Contested

SPECIAL COMPETITIVE STUDIES PROJECT

		has an early lead in this emerging field, however PRC firms are gearing up with their own launches.		
 Energy Generation & Storage	Fusion Energy	<table border="1"> <tr> <td>U.S.-Lead</td> <td>Trending U.S.</td> </tr> </table> <p>Significant commercial activity points to a U.S. lead in achieving the first demonstration of commercially relevant fusion. However, once a demonstration has taken place, the PRC would likely be ready to rapidly catch up and scale and commercialize fusion.</p>	U.S.-Lead	Trending U.S.
	U.S.-Lead	Trending U.S.		
Advanced High-Capacity Batteries	<table border="1"> <tr> <td>PRC-Lead</td> <td>Trending PRC</td> </tr> </table> <p>China is currently leading in advanced high-capacity batteries based on the dominance of PRC firms in both mining and processing the essential critical minerals, and their significant share of global lithium-ion battery production. Battery experts estimate that the United States has fallen about 10 years behind the PRC.</p>	PRC-Lead	Trending PRC	
PRC-Lead	Trending PRC			
 Compute	Quantum Computing	<table border="1"> <tr> <td>U.S.-Lead</td> <td>Contested</td> </tr> </table> <p>The United States is the current leader when considering demonstrated technical progress as measured by teams who have built machines demonstrating quantum advantage. PRC researchers are likely at technical parity with those in the United States in superconducting qubits, and are continuing to invest heavily.</p>	U.S.-Lead	Contested
	U.S.-Lead	Contested		
Semiconductors	<table border="1"> <tr> <td>Contested</td> <td>Trending U.S.</td> </tr> </table> <p>The United States leads in multiple inputs to the production process, but both the United States and the PRC lag behind industry leaders based in third countries in cutting-edge production. China is projected to dominate lagging-edge production by the end of the decade. However, U.S.-based firms are global leaders in chip design and new U.S. export controls may well cause China serious mid-term setbacks.</p>	Contested	Trending U.S.	
Contested	Trending U.S.			
 Convergence	Advanced Manufacturing	<table border="1"> <tr> <td>Contested</td> <td>Trending PRC</td> </tr> </table> <p>The United States and China both face workforce challenges. The United States retains a lead in robotics density even as China is automating manufacturing at a much higher rate. Key enabling technologies, including semiconductors and 5G systems, are either contested or favor the PRC. The U.S. relative share of advanced industries declined by nearly 16 percent between 1995 and 2018.</p>	Contested	Trending PRC
	Contested	Trending PRC		
Commercial Drones	<table border="1"> <tr> <td>PRC-Lead</td> <td>Trending PRC</td> </tr> </table> <p>As of 2021, PRC firms possess up to 63 percent of the commercial drone market. PRC-based DJI alone held over 50 percent of the market.</p>	PRC-Lead	Trending PRC	
PRC-Lead	Trending PRC			

The Systems: Comparing U.S. and PRC Innovation Ecosystems

Technology gaps manifest as a form of national power. But the primary determinant of today's international competition that drives those gaps is a contest of innovation ecosystems. The core actors – or innovation nodes – within the U.S. and PRC ecosystems are increasingly similar, but their relative weight and the relationships between them differ. The outcome of the competition will be determined by which system can better leverage its respective innovation geometry.

The PRC's Approach to Innovation: Four Key Differences

China's science and technology (S&T) planners have studied the U.S. ecosystem.⁴⁴ They seek to imitate it where they believe it works best and avoid its perceived failings. As a result, the core actors in China's ecosystem look increasingly similar to those in the United States. Many Chinese universities today produce world class research.⁴⁵ The PRC hosts a robust startup scene engaged in a diverse array of industries.⁴⁶ Large Chinese corporate research and development (R&D) labs also produce novel advances in frontier fields such as AI and quantum computing.⁴⁷ Robust government funding for science and technology research⁴⁸ and a network of state key laboratories that provide important infrastructure⁴⁹ further bolster Beijing's position. Venture capital (VC) has also emerged as a key driver of PRC innovation, to the tune of a record \$130.6 billion invested in 2021.⁵⁰ Increasingly, the PRC, just like the United States, is striving to properly incentivize key actors in its innovation system to better align with national priorities. However, China's approach has differed from the United States' in four key ways.

First, the PRC has tried to align venture capital with national priorities.⁵¹ Both the United States and the PRC face the challenge of aligning investors behind strategic technology areas. As the focus of technology development shifts from the realm of the digital to also include the physical and biotechnical,⁵² innovation will require higher capital expenditures and longer timelines.⁵³ In the PRC, local and provincial governments have sought to pair government funds with private

⁴⁴ Fang Aiqing, *The Formula For Success*, China Daily (2021).

⁴⁵ See Caroline S. Wagner, et al., [A Discussion of Measuring the Top-1% Most-Highly Cited Publications: Quality and Impact of Chinese Papers](#), *Scientometrics* (2022).

⁴⁶ Liza Lin, et al., [China's Startups Are Awash With Money as Beijing Shifts Focus to 'Hard Tech'](#), *Wall Street Journal* (2022).

⁴⁷ Craig Smith, [Competing Visions Underpin China's Quantum Computer Race](#), *IEEE Spectrum* (2021); Shuohuan Wang, et al., [ERNIE 3.0 Titan: Exploring Larger-Scale Knowledge Enhanced Pre-Training for Language Understanding and Generation](#), arXiv (2021).

⁴⁸ PRC funding for R&D is second only to the United States in the world, rising steadily over the past decade to be 2.4% of China's GDP by 2020, and \$564 billion in 2020 versus 3.45% of GDP and \$660 billion in the United States. Figures in 2015 USD in constant PPP prices. [Gross Domestic Spending on R&D](#), OECD (last accessed 2022).

⁴⁹ Emily Weinstein, et al., [China's State Key Laboratory System](#), Center for Security and Emerging Technology (2022).

⁵⁰ Coco Liu, [China VC Funding Hits Record \\$131 Billion Despite Crackdown](#), *Bloomberg* (2022).

⁵¹ Emily de La Bruyère & Nathan Picarsic, [The Weaponization of Capital: Strategic Implications of China's Private Equity/Venture Capital Playbook](#), Foundation for the Defense of Democracies (2022).

⁵² [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 170 (2022).

⁵³ See Massimo Portincaso, et al., [The Deep Tech Investment Paradox: A Call to Redesign the Investor Model](#), Boston Consulting Group and Hello Tomorrow at 35 (2021).

capital through “guidance funds” in strategically important sectors.⁵⁴ Additionally, in 2022, Beijing began to issue a “traffic light system” of regulations aimed at guiding VC investment into sectors Beijing has identified as strategically important.⁵⁵ America, conversely, has recognized the power of the VC model,⁵⁶ but has been more blasé about private venture firms’ strategic significance.⁵⁷ While the efficacy of such an approach remains to be seen, Beijing’s more intensive hand in shaping the development of its technology sector⁵⁸ represent its response to the market’s failure to naturally invest in “deep tech” projects.⁵⁹

Second, the PRC pursues a different role for the government in creating the conditions for innovation, based on its desired end state.⁶⁰ The PRC’s innovation strategy is motivated by the desire to close its technology gaps with the rest of the world and ultimately to ensure the dominance of PRC firms in all technology fields.⁶¹ While the United States pursues certain technologies for strategic gain, it is not an all-encompassing lens. As a result, PRC state actors are significantly more hands-on throughout the innovation cycle. Additionally, PRC technology firms compete for dominance often not on the basis of technical merits alone but with significant state assistance through a series of both licit and illicit means including: subsidies, restrictions on foreign competition, and forced technology transfer.⁶²

Third, in areas deemed strategically important, Beijing designates national champions. Beijing has extended this practice to include small firms in priority emerging sectors through its “little giants” program, which designates specific startups as eligible for tax breaks and less likely to be

⁵⁴ [The Rise of China’s VC-Industrial Complex](#), *The Economist* (2022) (“Between 2015 and 2021 around 2,000 so-called ‘government guidance funds’ collectively raised almost \$1 [trillion]”).

⁵⁵ The spotlight system also discourages investment in sectors that have traditionally yielded higher returns on shorter timelines, such as internet and software platforms. See Trivium Tech Quick Take, Trivium China (2022).

⁵⁶ The U.S. Government has appreciated the power of the venture capital model, supporting several government affiliated actors, like In-Q-Tel. See [About IQT](#), In-Q-Tel (last accessed 2022).

⁵⁷ Emily de La Bruyère & Nathan Picarsic, [The Weaponization of Capital: Strategic Implications of China’s Private Equity/Venture Capital Playbook](#), Foundation for the Defense of Democracies at 1 (2022); Elisabeth Braw, [How China Is Buying Up the West’s High-Tech Sector](#), *Foreign Policy* (2020).

⁵⁸ Ngor Luong, et al., [Understanding Chinese Guidance Funds](#), Center for Security and Emerging Technology (2021); [China’s Big Tech Crackdown: A Timeline](#), TheChinaProject (2022).

⁵⁹ “Deep tech” or “tough tech” portends a large impact, but requires “a long time to reach market-ready maturity” and significant capital to develop and scale. Massimo Portincaso, et al., [The Dawn of the Deep Tech Ecosystem, Boston Consulting Group and Hello Tomorrow](#) at 2 (2019). See also [Building a 21st-Century American Economy: The Role of Tough Tech in Ensuring Shared, Sustainable Prosperity](#), The Engine & Belfer Center for Science and International Affairs at 10 (2020).

⁶⁰ [Key Takeaways From Xi Jinping’s Two-Hour Speech](#), Bloomberg (2022). Xi Jinping reaffirmed Beijing’s commitment to S&T development as foundational for China’s long term security and economic growth, and signaled that Beijing intends to continue to take an active role.

⁶¹ Robert Atkinson, [Confronting Chinese Innovation Mercantilism](#), Information Technology & Innovation Foundation (2012).

⁶² Sean O’Connor, [How Chinese Companies Facilitate Technology Transfer from the United States](#), U.S.-China Economic and Security Review Commission (2019); Greg Levesque, [China’s Evolving Economic Statecraft](#), *The Diplomat* (2017); Mark Wu, [The “China, Inc.” Challenge to Global Trade Governance](#), *Harvard International Law Journal* (2016).

subject to regulatory crackdown to further encourage private investment.⁶³ The PRC’s approach of providing government subsidies to such firms⁶⁴ and protecting the domestic Chinese market to grow national technology champions⁶⁵ gives Beijing an advantage when trying to accelerate adoption of PRC origin technology or helping firms overcome otherwise adverse market conditions.

Fourth, the PRC compels “military-civil fusion” (MCF) in its innovation ecosystem.⁶⁶ In contrast to U.S. models of public-private partnership through which companies can provide support to the defense industrial base and other national security priorities on a voluntary basis, the PRC’s MCF strategy enables Beijing to incentivize, co-opt and, if needed, compel private actors to support national objectives.⁶⁷ Through a combination of MCF policies and incentives, and a system of PRC laws that requires all individual and companies to assist with national security and intelligence work if required,⁶⁸ Beijing can compel private enterprises to turn over technology to state actors for military purposes or to support broader state goals.⁶⁹ Significant portions of the MCF strategy center on incentives – such as industrial zones and “MCF funds” – designed to encourage private firms to respond to and serve government needs and compete with the state-owned defense enterprises.⁷⁰

Harnessing America’s New Geometry of Innovation

While the PRC is leveraging its innovation elements, the United States is leaving potential on the table. A highly effective innovation triangle of government, industry, and academia supported U.S. technology leadership throughout the Cold War.⁷¹ However, the geometry of the U.S. ecosystem has evolved over the past thirty years to include new actors such as venture capital and, with the rise of the internet, “the crowd.” To hold its own in this new era of strategic competition, the United States must reorient around a new geometry of innovation. Stepping

⁶³ See [China’s ‘Little Giants’ Are Its Latest Weapon in the U.S. Tech War](#), Bloomberg Law (2022).

⁶⁴ Chuin-Wei Yap, [State Support Helped Fuel Huawei’s Global Rise](#), Wall Street Journal (2019). For a broader review of the PRC’s subsidy and industrial policy, see Gerard DiPippo, et al., [Red Ink: Estimating Chinese Industrial Policy Spending in Comparative Perspective](#), Center for Strategic and International Studies (2022).

⁶⁵ Agatha Kratz & Janka Oertel, [Home Advantage: How China’s Protected Market Threatens Europe’s Economic Power](#), European Council on Foreign Relations at 4-10 (2021).

⁶⁶ [Military-Civil Fusion](#), U.S. Department of State (2020).

⁶⁷ Greg Levesque, [Commercialized Militarization: China’s Military-Civil Fusion Strategy](#), National Bureau of Asian Research (2021).

⁶⁸ Murray Scott Tanner, [Beijing’s New National Intelligence Law: From Defense to Offense](#), Lawfare (2017); [Remarks by William Evanina](#), International Legal Technology Association LegalSEC Summit at 2 (2019).

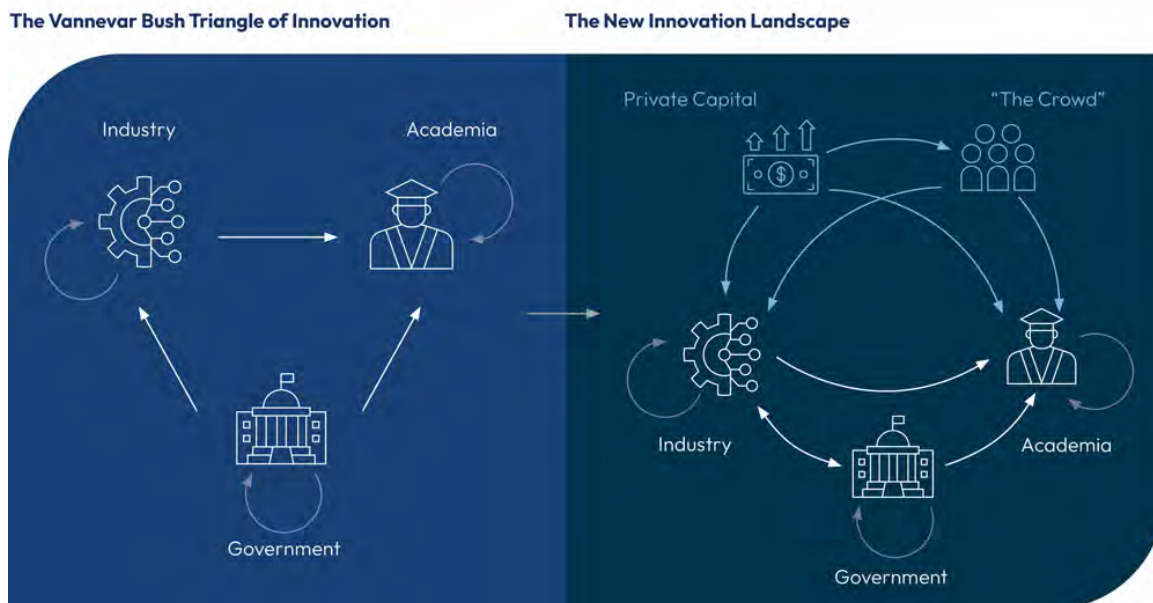
⁶⁹ Elsa Kania & Lorand Laskai, [Myths and Realities of China’s Civil Military Fusion Strategy](#), Center for a New American Security (2021).

⁷⁰ Scott Kennedy, [China’s Military-Civil Fusion Funds: Big but Not Necessarily Effective](#), Center for Strategic and International Studies (2019).

⁷¹ On that innovation triangle, see Walter Isaacson, [The Sources of America’s Innovative Edge](#), Aspen Institute at 169-75 (2019) (paper in Technology and National Security: Maintaining America’s Edge).

through each node of the U.S. innovation ecosystem illustrates the gaps and opportunities that a new model must address.

New Geometry of Innovation



America was the technological superpower of the 20th Century. Today, it is one of multiple great tech powers, many of whom are also U.S. partners and allies.⁷² America's 20th Century technology edge stemmed in significant part from the federal government's role. Following World War II, the U.S. Government assumed considerable responsibility for funding basic research, cultivating scientific talent, and developing a national science policy for the nation.⁷³ The creation of the National Science Foundation was a significant step for government-supported science. The Soviet launch of Sputnik in 1957 added the urgency of an international space race and inspired investments to cultivate S&T talent.⁷⁴ America's Cold War S&T entities possessed clear missions, providing focus and a bias towards solving grand challenges. These initiatives generated breakthroughs that pay dividends to this day.⁷⁵ Since the 1980s, however, the federal government's relative contribution to R&D has diminished.⁷⁶ While *total* R&D

⁷² [Global Science and Technology Capabilities](#), U.S. National Science Foundation (2020).

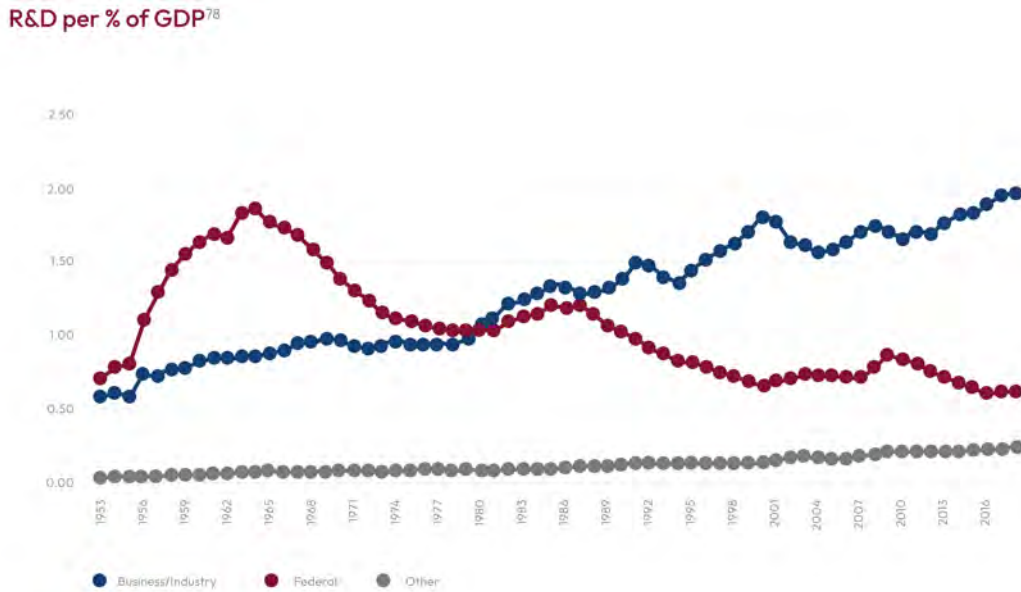
⁷³ Vannevar Bush conceived of a federal entity that would "promote a national policy for scientific research and scientific education." Vannevar Bush, [The Endless Frontier - 75th Anniversary Edition](#), U.S. National Science Foundation at 36-37 (2020).

⁷⁴ See Pub. L. 85-864, [National Defense Education Act](#) (1958). On the importance of "people" to S&T leadership, see [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project at 40-46 (2022); [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 64-67 (2022).

⁷⁵ See e.g., [Going to the Moon Was Hard - But the Benefits Were Huge, for All of Us](#), National Aeronautics & Space Administration (2019); Ben Tarnoff, [How the Internet Was Invented](#), The Guardian (2016).

⁷⁶ Federal government funded R&D dropped from a peak of 1.86 percent of U.S. GDP in 1964 to 0.62 percent of GDP in 2018. See [National Patterns of R&D Resources: 2017-18 Data Update](#), U.S. National Science Foundation at Table 1 (2020).

spending in the United States has risen, the private sector spending has driven almost all of this increase.⁷⁷ As the government’s role driving the S&T agenda has diminished, so too has its ability to harness new innovation actors that have emerged.



Simultaneously, new actors have emerged as the locus of research and development, creating alternatives to universities, national laboratories, and established industry. In many fields, startup firms are where the most cutting-edge technology development is occurring.⁷⁹ Venture capital-backed public companies, not major industry leaders, accounted for 46 percent of total U.S. R&D spending across government, academic, and private companies in 2019.⁸⁰ Looking only at the overall picture would lead one to believe that the situation is healthy. However, a closer look suggests that is not the case.

For industry’s part, R&D spending focuses primarily on applied research and development in narrow fields, rather than the broader basic research that drives step changes in technological progress.⁸¹ At the same time, traditional U.S. corporate labs have withered.⁸² Such S&T

⁷⁷ [Building a 21st-Century American Economy: The Role of Tough Tech in Ensuring Shared, Sustainable Prosperity](#), The Engine & Belfer Center for Science and International Affairs at 5 (2020); Paul Scharre & Ainikki Riikonen, [Defense Technology Strategy](#), Center for a New American Security at 7-8 (2020).

⁷⁸ [National Patterns of R&D Resources: 2017-18 Data Update](#), U.S. National Science Foundation at Table 1 (2020).

⁷⁹ See Antoine Gourévitch, et al., [Deep Tech and the Great Wave of Innovation](#), Boston Consulting Group (2021).

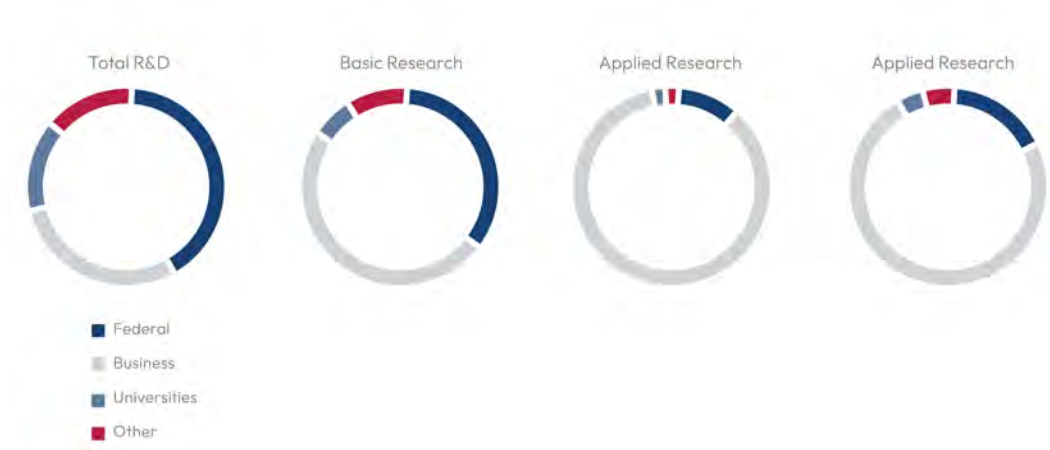
⁸⁰ Will Gornall & Ilya A. Strebulaev, [The Economic Impact of Venture Capital: Evidence from Public Companies](#), SSRN (2021).

⁸¹ Allen Wagner, [Why Aren’t VCs Funding the Future?](#), PitchBook (2014).

⁸² See Alexander Tullo, [Why DuPont Shrunk Its Central Research Unit](#), Chemical and Engineering News (2016) (DuPont Central Research and Development “was, for many years, arguably the world’s center of fundamental research in

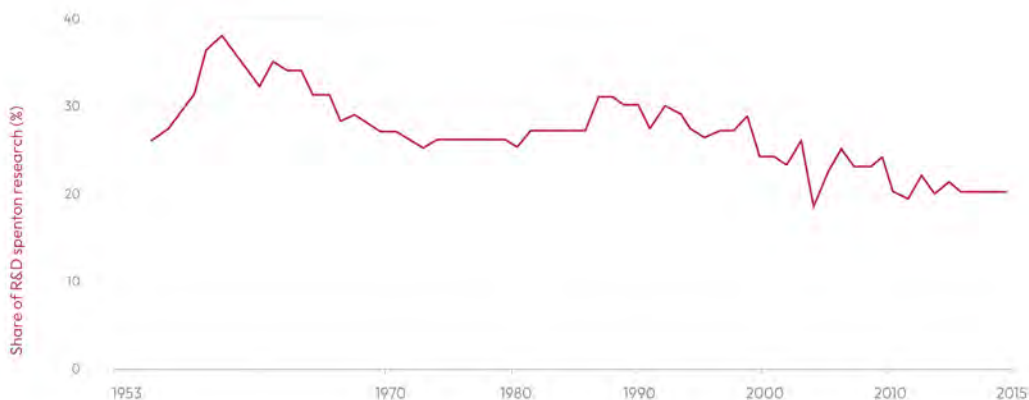
institutions helped bridge industry and academia as homes to both basic and applied research. However, the corporate withdrawal from scientific research, particularly capital-intensive research subsidized by their other operations, has left novel, high-cost research to universities, startups, and National Labs rather than their own internal teams.⁸³ The result has been a more splintered innovation ecosystem.

Character of R&D, 2020⁸⁴



Corporate R&D in the U.S. Has Become Less About Research⁸⁵

The share of basic and applied research in total business R&D expenditures in 2015 was about half of what it was in the late 1950s.



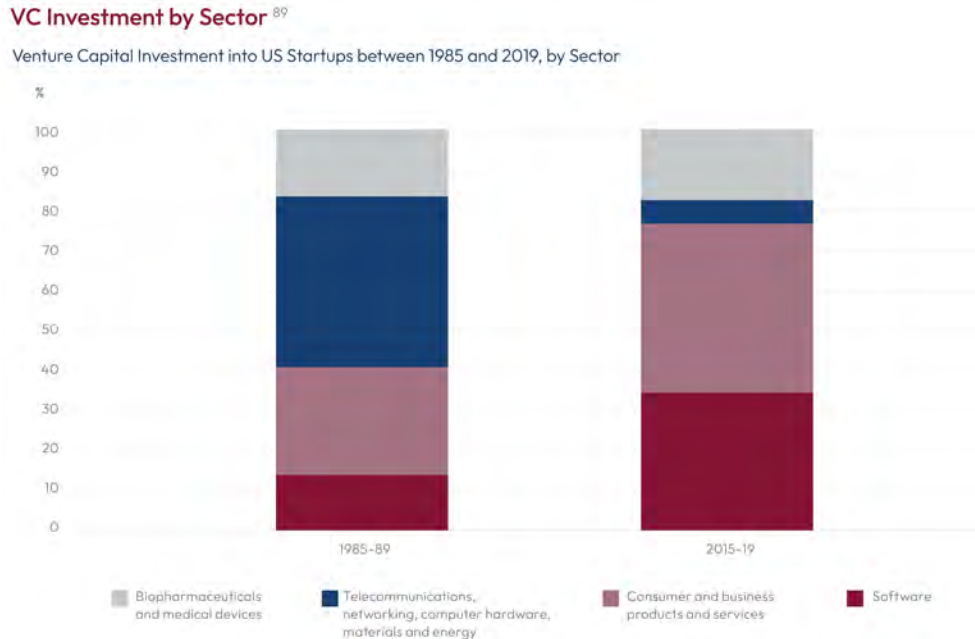
organometallic chemistry,' noted Harvard chemistry professor George M. Whitesides.”); Jon Gertner, [The Idea Factory: Bell Labs and the Great Age of American Innovation](#), Penguin Books (2012) (discussing the rise and fall of Bell Labs); Tekla Perry & Paul Wallich, [Xerox PARC’s Engineers on How They Invented the Future – And how Xerox Lost It](#), IEEE Spectrum (1985).

⁸³ As an example of the degree to which corporate labs rivaled their academic counterparts, AT&T’s Bell Labs had 14 Nobel Prize and 5 Turing Award winners among its alumni. See Ashish Arora, et al., [Why the US Innovation Ecosystem is Slowing Down](#), Harvard Business Review (2019). On the decline in corporate investment in basic research, see [Innovation and National Security: Keeping Our Edge](#), Council on Foreign Relations at 21–22 (2019).

⁸⁴ John F. Sargent Jr., [U.S. Research and Development Funding and Performance: Fact Sheet](#), Congressional Research Service at 5 (2022).

⁸⁵ Ashish Arora, et al., [Why the US Innovation Ecosystem is Slowing Down](#), Harvard Business Review (2019).

Similarly, the rise of VC firms as a primary source of commercial innovation funding has further jolted the funding landscape. Yet, venture capital’s focus on relatively shorter-term returns⁸⁶ has meant that, to date, it has largely stayed away from deep tech and commercialization of basic R&D⁸⁷ – both of which require enormous patience and appetite for risk.⁸⁸



Nor have VC firms been inherently equipped to navigate the increasingly murky geopolitics of strategic technologies. Venture capital came into its own as truly global force in a period of waning geopolitics,⁹⁰ making it traditionally less accustomed to considering geopolitical concerns.

⁸⁶ While venture capital is seen as a long-term player in much of the investment world, everything is relative. VC funds are often designed on ten-year timeframes, with even shorter windows for making investments and then cultivating them. Yet, deep tech ventures can easily require more than a decade in time. See Massimo Portincaso, et al., [The Deep Tech Investment Paradox: A Call to Redesign the Investor Model](#), Boston Consulting Group and Hello Tomorrow at 12 (2021).

⁸⁷ For example, approximately 75 percent of VC investment into U.S. startups in 2019 went to software and consumer and business products, with less than 10 percent going to startups working on sectors such as telecommunications, networking, computer hardware, and energy. See Josh Lerner & Ramana Nanda, [Venture Capital's Role in Financing Innovation: What We Know and How Much We Still Need to Learn](#), Journal of Economic Perspectives at 247 (2020).

⁸⁸ [Building a 21st-Century American Economy: The Role of Tough Tech in Ensuring Shared, Sustainable Prosperity](#), The Engine & Belfer Center for Science and International Affairs at 10 (2020) (noting that deep tech often “falls outside of the exclusive ability of most private sector firms,” leaving that critical frontier area underfunded).

⁸⁹ Josh Lerner & Ramana Nanda, [Venture Capital's Role in Financing Innovation: What We Know and How Much We Still Need to Learn.](#), Harvard Business School at 29(2020).

⁹⁰ See Emily de La Bruyère & Nathan Picarsic, [The Weaponization of Capital: Strategic Implications of China’s Private Equity/Venture Capital Playbook](#), Foundation for the Defense of Democracies (2022); Sebastian Mallaby, [The Power Law](#), Penguin Press at 392-95 (2022).

As a result, the U.S. S&T ecosystem has become largely untethered from geopolitical rivalry and functions with relative indifference to the strategic implications of technology developments.⁹¹

Furthermore, technology itself has created a new node in the innovation geometry by enabling the individual and “the crowd” to play a more direct role in research and funding. Digital networks have allowed us to crowdfund, fastgrant, and decentrally organize research and funding for scientific development.⁹² New forms of “crowd-based” funding⁹³ and research collectives using blockchain-based decentralized autonomous organizations⁹⁴ have arisen because the existing system has not been working sufficiently fast to keep pace with innovation.⁹⁵

New Technologies, New Innovation Models

Further complicating today’s geometry of innovation is the growing complexity and convergence of various technologies. There is both a “cutting edge” in AI and in convergent spaces like advanced manufacturing that draw on the leading advances in hardware, networks, robotics, and AI.⁹⁶ This has led to a reconceptualization of the innovation process from a linear flow of knowledge and discovery to a dynamic interaction between basic and applied research – often across disciplines – to solve complex problems.⁹⁷ Such an approach has enabled startups and “moonshot factories” to drive technological progress in novel ways, such as mixing core technology teams and driving “use-inspired research” to solve specific challenges.⁹⁸ While these models often outpace government labs, many draw inspiration from government. The “Advanced Research Project Agency” model pioneered by DARPA,⁹⁹ for example, has become a popular method for blending technology disciplines and incentivizing novel research to solve challenges.

⁹¹ See Kjartan Rist, [Geopolitical Tension And Market Uncertainty Will Not Diminish VC Aspirations](#), Forbes (2022). Nor is venture capital alone in trying to continue their previous activities in a more fraught world. See Johan Öberg, et al., [What PE Needs to Know About Geopolitics and Tech](#), Boston Consulting Group (2022).

⁹² See [Fast Funding for COVID-19 Science](#), Fast Grants (last accessed 2022); Biz Carson, [Bessemer Wants to Put Venture Scouting on the Blockchain](#), Protocol (2022); Sarah Hamburg, [A Guide to DeSci, the Latest Web3 Movement](#), Future (2022); Jeffrey Brainard, [Want to Crowdfund Your Science? New Study Hints At Who Is Successful](#), Science (2018); Derek Thompson, [Silicon Valley’s New Obsession: Science Funding](#), The Atlantic (2022).

⁹³ Elliott Hershberg & Jocelynn Pearl, [Gassing the Miracle Machine](#), The Century of Biology (2022).

⁹⁴ Sarah Hamburg, [A Guide to DeSci, the Latest Web3 Movement](#), Future (2022).

⁹⁵ [Dr. No Money: The Broken Science Funding System](#), Scientific American (2011).

⁹⁶ For more on advanced manufacturing, see Appendix B of this report.

⁹⁷ Gretchen Jordan, et al., [Innovation Isn’t a Frontier—It’s an Ecosystem](#), Issues in Science and Technology (2020).

⁹⁸ See [Moonshot Thinking](#), X (last accessed 2022); Natasha Mascarenhas, [The Biggest Moonshots in YC’s S22 Batch](#), Tech Crunch (2022) (discussing Y-Combinator’s 2022 cohort); Conrad Duncan, et al., [Imperial College London to Accelerate “Deep Tech” Moonshots to Market](#), Imperial College London (2022); Mary Jo Foley, [Microsoft Research Special Projects Group Tipped to Take on Google X](#), ZDNet (2014).

⁹⁹ Regina Dugan & Kaigham Gabriel, [Changing the Business of Breakthroughs](#), Issues in Science and Technology (2022).

Lastly, these changes have unfolded against a backdrop of a more globalized S&T landscape. Following World War II, America was the unquestioned global science leader. Today, U.S. researchers often collaborate with teams scattered around the world. Further, this new landscape is not bipolar in composition. Multiple key actors exist. Despite being the S&T heavy weights, the United States and China account for less than 50 percent of all global scientific research.¹⁰⁰ The majority of the remaining research is driven by American allies and partners, including in the European Union, South Korea, and Japan. While the United States has less control over the direction of this research, there are tremendous opportunities – and a comparative advantage over the PRC – for America to continue partnering with like-minded countries to drive technological progress.¹⁰¹

Mastering America's New Innovation Geometry

Dr. Vannevar Bush, who led the former U.S. Office of Scientific Research and Development and dubbed “Science – the Endless Frontier,” wrote in 1945 “[t]here are areas of science in which the public interest is acute but which are likely to be cultivated inadequately if left without more support than will come from private sources.”¹⁰² To master this new geometry of innovation, the U.S. Government will have to do more than return to its role as the primary funder of basic science and procurer of military technologies. It must revise how it incentivizes research and development, reforming not only how it allocates funding but to who, to where, and how often.¹⁰³ In an increasingly complex ecosystem with additional actors and converging technologies, the U.S. Government’s role both as a convener and agenda setter is more important than ever.¹⁰⁴ A number of alternative models for funding and organizing research have emerged in recent years to try to fill the gap.¹⁰⁵ Yet none of these models will be adequate on their own, especially not in ensuring that technological progress is consistently incentivized to serve the national interest.

This is not to say that the government should control those new sources of innovation or funding. Or that the state alone should direct science for the country. Rather, it is about reasserting the necessary role of government in helping shape scientific progress that is deeply intertwined with questions of public good. Much has changed since Vannevar Bush’s time, but the essential fact remains – scientific and technological progress for the betterment of the United States and humanity requires the federal government to be an active steward of science. Steeling itself in the 1940s for a prolonged international competition, America had to develop the necessary

¹⁰⁰ China (23%) and the United States (16%) accounted for 39% of all research publications in 2020. [The State of U.S. Science and Engineering 2022](#), U.S. National Science Foundation (2022).

¹⁰¹ [The State of U.S. Science and Engineering 2020](#), U.S. National Science Foundation (2020).

¹⁰² Vannevar Bush, [The Endless Frontier – 75th Anniversary Edition](#), U.S. National Science Foundation at 9 (2020).

¹⁰³ Adam Marblestone, et al., [Unblock Research Bottlenecks with Non-Profit Start-Ups](#) (2022).

¹⁰⁴ Melissa Flagg & Paul Harris, [System Re-Engineering](#), Center for Security and Emerging Technology (2020).

¹⁰⁵ Alexey Guzey, [How Life Sciences Actually Work: Findings of a Year-Long Investigation](#), Guzey.com (2018); [Ideas on How to Improve Scientific Research](#), Medium (2019); John Hollis, [Fast Grants to Aid in the Development of a Pan-Coronavirus Vaccine](#), George Mason University (2021).

“bureaucratic sinews . . . without ruining the country’s democratic soul.”¹⁰⁶ The nation must achieve that feat again.

An International Competition Demands a Different Type of Science and Technology Policy Stewardship

The U.S. Government does not lack institutions engaged in science and technology policy. To name only a few, the National Security Council (NSC), the Office of Science and Technology Policy (OSTP), and the National Science and Technology Council (NSTC) all support the President’s policy agenda.¹⁰⁷ Yet, the results have been an America that is increasingly playing catch-up in key technology sectors across administrations.

Until only quite recently, the U.S. science and technology ecosystem was not operating under a techno-economic competition paradigm. Recognition of geopolitical competition – with technology is its core – is a still new development.¹⁰⁸ The lack of a competitive paradigm has uncut any rationale for institutional reform, and too often siloed questions of technology and national security.¹⁰⁹ Simultaneously, inconsistent presidential engagement and integration of science and technology institutions into core White House decision-making has undermined long-term strategic analysis and planning.¹¹⁰ Finally, the government science and technology policy process has left too little room for regular private sector engagement that is systematic and coordinated at the leadership level. National security restrictions have amplified this challenge by encumbering NSC engagement with private actors despite the latter being the “primary drivers of research and development of new technology.”¹¹¹

¹⁰⁶ Hal Brands, [The Twilight Struggle](#), Yale University Press at 174 (2022).

¹⁰⁷ See John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 2, 9-10 (2020); [National Science and Technology Council](#), The White House (last accessed 2022).

¹⁰⁸ See [U.S. National Security Strategy](#), The White House at 17 (2017) (elevating the role of geopolitical competition). On the subsequent recognition of technology at the center of that competition, see, e.g., James Lewis, [Technological Competition and China](#), Center for Strategic and International Studies (2018); Kevin Rudd, [A New Era of U.S.–China Competition Calls for New Rules](#), Axios (2018). The most recent National Security Strategy has reaffirmed that outlook. [National Security Strategy](#), The White House at 32 (2022).

¹⁰⁹ Brendan McCord & Zoe Weinberg, [Emerging Technology & The Future of the National Security Council](#), Stanford University Center for International Security and Cooperation at 25 (2020).

¹¹⁰ See William Berry, et al., [Reform of the National Security Science and Technology Enterprise](#), Center for Technology and National Security Policy, National Defense University at 9 (2008); Henry Kelly, et al., [Flying Blind: The Rise, Fall, and Possible Resurrection of Science Policy Advice in the United States](#), Federation of American Scientists at 29-30 (2004).

¹¹¹ Brendan McCord & Zoe Weinberg, [Emerging Technology & The Future of the National Security Council](#), Stanford University Center for International Security and Cooperation at 25 (2020).

PART II:

A Complete Competition Model for America

When prescribing how America could win a long-term technology competition, thinking in terms of “position” offers a guide to building winning equations in sectors that matter most to national power. Whether seen from the business world lens of the Positioning School¹¹² or strategy classics by Thucydides¹¹³ or Sun Tzu,¹¹⁴ winning strategies take the form of dominant positions in the relevant competition. By studying the environment (or market) and the players in it, a wise entity deliberately chooses what positions to occupy for competitive advantage and then drives organizational structure to achieve them.¹¹⁵ At the national level, the American democracy often secures strategic technology positions by national endeavors that translate latent power into active power to preserve peace, foster economic opportunity, advance scientific frontiers, and – when necessary – win wars.

History suggests that identifying bold national technology goals and a process for pursuing them are one practical way to move the entire U.S. innovation ecosystem toward positions of national advantage. For example, the Apollo Program famously shifted space power toward the United States when it was at risk of losing a strategic tech race. It was a lofty goal to strap human beings to a Saturn V rocket, land them precisely on the moon, and return them alive using a computer less powerful than a modern calculator.¹¹⁶ However, the endeavor raised the bar on the country’s collective sense of what was possible and attracted the nation’s best minds to the challenge. The National Aeronautics and Space Administration (NASA) itself was born out of an international competition organization, the National Advisory Committee for Aeronautics (NACA), that was created in 1917 because the United States was falling behind Europe in aviation.¹¹⁷ The elite engineering culture built over decades at the NACA transferred into NASA as a government start-up and was filled with the intellectual resources of the private sector, including from friendly nations like Canada.¹¹⁸ This collaboration between the government, the private sector, and allies and partners was integral to NASA’s success in the Apollo program and continues to play an important role in executing NASA’s missions today.

¹¹² See Henry Mintzberg, et al., [Strategy Safari](#), Prentice Hall at 85 (2009).

¹¹³ See Thucydides, [History of the Peloponnesian War](#), Penguin Classics at Book 1, Section 44-45 (1972). On interpreting Thucydides through the lens of position and relative advantage, see Donald Kagan, [On The Origins of War and the Preservation of Peace](#), Anchor Book at 44-45 (1996).

¹¹⁴ See Sun Tzu, [The Art of War](#), Shambhala (Translator, Thomas Cleary) (2003). For an example connecting Sun Tzu to relative advantage, see Zhongqi Pan, [Guanxi, Weiqi and Chinese Strategic Thinking](#), Chinese Political Science Review at 308-10 (2016).

¹¹⁵ Henry Mintzberg, et al., [Strategy Safari](#), Prentice Hall at 88 (2009).

¹¹⁶ Graham Kendall, [Would Your Mobile Phone be Powerful Enough to Get You to the Moon?](#), The Conversation (2019).

¹¹⁷ Charles Murray & Catherine Bly Cox, [Apollo: The Race to the Moon](#), Simon and Schuster at 25 (1989). NACA drew talent including Vannevar Bush and Orville Wright.

¹¹⁸ Mariana Mazzucato, [Mission Economy](#), Harper Business Press at 93-95 (2021) (discussing NASA-private sector relationship); Charles Murray & Catherine Bly Cox, [Apollo: The Race to the Moon](#), Simon and Schuster at 33-35 (1989) (illustrating the role of talent from U.S. allies in the space program).

There are several other examples of a public target being achieved with private-sector know-how. The Second Offset Strategy in the Department of Defense successfully undercut Soviet operational planning to attack Europe based on new U.S. capabilities such as precision targeting, wide-area surveillance, and stealth aircraft.¹¹⁹ ARPANET began as a modest communications program in the Pentagon's DARPA before converging with private sector innovation in global networks to usher in the digital age.¹²⁰ Operation WARP SPEED overcame organizational barriers and incentivized U.S. vaccine manufacturers to produce top vaccines at scale, protecting Americans and expanding global access to the vaccines.¹²¹ Initiatives such as these illustrate the power of audacious technology goals to not only reach specific objectives, but also to yield beneficial innovation spillovers that bolster the country's fundamentals and enhance its overall position.

How does the nation decide it is time for greater unity of effort to achieve positional advantage? Positional changes between nations may arrive by *cumulative effects* as breakthroughs accrue quietly over time. For example, as illustrated in the discussion of Gaps, China has accumulated leading positions in sectors like 5G network components, advanced batteries, and commercial drones. Positional advantage between nations also changes via *disruptive technology investments* or bets. In this approach, episodic breakthroughs in the most important technologies of the time drive both advantage as well as perceptions of power. At the end of World War II, Germany's rockets were better than those of the United States,¹²² but nuclear weapons became the technology that ended the war and dominated the next half century of security policy and defense spending. In contrast to advantages accrued over time, the Apollo Program, the Second Offset strategy, and more recently Covid vaccines represented disruptive technology bets that achieved leadership in the areas that mattered most at the time.

Both cumulative and disruptive effects drive how a democracy wakes up to a competition. Sometimes rising to an international challenge results from a *rude awakening* of outside forces in dramatic events like the War of 1812, Pearl Harbor, or 9/11. At other times, the need to wake up appears *gradually over time* and the American response is more like a dawning. It is harder to place the precise time in gradually mounting competitions, such as the influence of communism during the Cold War or the techno-economic competition that is playing out today.

¹¹⁹ Michael J. Sterling, [Soviet Reactions to NATO'S Emerging Technologies for Deep Attack](#), RAND Corporation at V (1985).

¹²⁰ [ARPANET](#), Defense Advanced Research Projects Agency (last accessed 2022).

¹²¹ Gina Colata & Henry Mueller, [Halting Progress and Happy Accidents: How the mRNA Vaccines Were Made](#), New York Times (2022); David Adler, [Inside Operation Warp Speed: A New Model for Industrial Policy](#), American Affairs (2021).

¹²² [V-2 Missile](#), Smithsonian National Air and Space Museum (last accessed 2022).

The United States can seize the high ground in that competition through a public-private model that harnesses current geometry of innovation. Playing to American strengths and leading with democratic values, the nation can combine the top-down leadership and bottom-up contributions of the nation’s brightest minds to build an engine of innovation and an arsenal of democracy for the 21st century.

The Process: A Public-Private Model for Technology Strategy

The United States will be hard to beat if it combines private and public sector thought leaders in a voluntary national process for developing competitive technology strategy. The ideal baseline public-private partnership (PPP) would leverage U.S. competitive advantages across the new geometry of the U.S. innovation ecosystem to include academic, government, industry, investors, and the crowd. When convened, innovation actors in these categories should collaborate across six basic technology competition functions in a methodical, but wholly voluntary, national process:

Six Functions of a Public-Private Model for Technology Strategy

Strategy Function: Asking the Right Questions

- **Why:** The questions policymakers ask inform the technologies they prioritize.
- **Who:** A White House-led Technology Competitiveness Council or alternative model organization.
- **How:** Using a Strategic Evaluation Framework.

Study Function: Building a National Horizon-Scanning Network

- **Why:** The cross-sector international competition demands systematic awareness and the majority of those answers are in the private sector.
- **Who:** Volunteer private sector actors from venture capital, universities, federally funded research and development centers (FFRDCs), strategy consultants, investment arms of major banks, think tanks, not-for-profit organizations, international institutions, authors, and journalists.
- **How:** Build and maintain a network including private sector horizon scanners who voluntarily offer technology forecasts to support policymakers.

Curate Function: Developing Detailed Technology Goals and Plans for U.S. Advantage

- **Why:** Fear of being wrong paralyzes leaders staring at long lists of emerging technologies.
- **Who:** Domestic and international technology thought leaders.
- **How:** Build and maintain a network of private sector technologists to envision what is possible, define bold and specific technology objectives, and support national action plans to achieve advantage.

Resource Function: Pooling Private Investor Logic and Interests

- **Why:** Investor logic and strategy supports how advantage plays out in domestic and international markets.

- **Who:** Venture capital, private equity, funds, foundations, crowd-sourcers, and traditional government actors.
- **How:** Build and maintain a network of private sector leaders across investment categories in the United States and democratic nations.

Implement Function: Overseeing and Supporting Implementation of Plans Across Administrations

- **Why:** Lack of policy continuity and technologies that span departments and agencies demands an accountable and empowered implementation arm.
- **Who:** The Technology Competitiveness Council or alternative model organization.
- **How:** Track and support national technology advantage plans and programs.

Organize Function: Learning from Each Step How to Craft an Endless Frontier 2.0 Charter

- **Why:** Each function of the competition process reveals high-order organization advantages that would combine to chart an Endless Frontier 2.0 charter for science and technology.¹²³
- **Who:** The combined private and public actors in all previous functions.
- **How:** Develop an Endless Frontier 2.0 vision that builds on the legacy of Vannevar Bush for what America’s innovation ecosystem could be and define tangible steps to move the nation there.

The Strategy Function: Asking the Right Questions

The Strategy Function of the process is required to sort out which technologies demand concerted whole-of-nation attention. The foundations of a national technology strategy process will rest upon policymakers’ ability to discern strategic signal from wider technology noise. There is no tried-and-true method for identifying which technology moves a nation should make. Any approach must account for multiple lenses which drive different priorities. Opportunity-based, threat-based, and comparative advantage-based lenses – as well as questions of short- and long-term horizons – can lead to different weighting schemes. This approach combines levels of analysis into a common method with three categories of strategy questions:

1. **Technology Dynamics:** Questions about the technology itself help to determine whether a technology is strategically important enough to warrant fostering a dominant national position. These questions assess a technology’s most sweeping potential, its impact in specific domains, and how its inherent characteristics will interact with national power.

¹²³ Vannevar Bush envisioned a government-enabled scientific research and development ecosystem, outlining a framework in his landmark report, “Science – The Endless Frontier.” See Vannevar Bush, [The Endless Frontier - 75th Anniversary Edition](#), U.S. National Science Foundation at 36-37 (2020). We are not alone in drawing on Bush’s legacy. His work helped inspire Senators Chuck Schumer and Todd Young and Representatives Ro Khanna and Mike Gallagher to propose the bipartisan, bicameral Endless Frontier Act in 2020, which was ultimately the source for many of the science and technology provisions found in the CHIPS and Science Act (Pub. L. 117-167).

2. **Rival Ecosystem:** Rival-focused questions consider the current state and potential trajectory of international competition over a technology area. China is a natural rival to consider for each of the questions below; however the framework does not preclude – and indeed encourages – consideration of other geopolitical rivals should they emerge.

3. **Domestic Ecosystem:** Questions about the domestic ecosystem’s strengths and weaknesses show where the American private sector is delivering on its own and where national action is necessary. The questions help identify models to learn from, latent potential for harnessing, the partners with whom to join forces, and the obstacles to overcome to ensure a strong U.S. position.

Strategic Evaluation Framework

These questions will be used to find strategic signal in the noise to define national technology goals to enhance American competitiveness in the 2025-2030 timeframe.

Technology Factors

Is this technology strategically important enough to warrant fostering a dominant national position?

- Could this technology yield a revolutionary breakthrough that upends existing paradigms or fundamentally changes the way the world works?
- Is this a general purpose technology (GPT) like electricity that could subfund or accelerate many other sectors?
- Does this technology present or solve a novel, foreseeable, and material existential national security threat?
- Could this technology alter the economic fundamentals of the United States? Relatedly, does this technology or program present massive spinoff potential?
- Could this technology change the military balance of power outright by its existence?
- Could this technology transform the means of production of information and/or the control of its flow in society?
- Does this technology possess "first-mover" criteria such as scarce factors of production, network effects, or other forms of potential lock-in.

Rival Factors

Are U.S. rivals positioned for strategic advantage in this technology?

- Are rivals ahead in this area? Is there a need for an offset/leapfrog move due to blindspots of U.S. commercial investment?
- Are rivals substantially trying to get ahead (strategy, invested, determined, aligned public and private efforts towards its development)?
- Are rivals likely to get ahead due to technology readiness level in their ecosystems compared with the U.S. ecosystem?
- Do rival economic/political systems obviously favor development of this technology over others (e.g. resource allocation, regulatory environment, norms)?
- Does this technology represent a major or potential front along clashing tech-spheres of influence?
- How will U.S. rivals react to U.S. development of or leadership in this technology? Does this technology intersect with weaknesses, organizational inertias, or fundamental asymmetries of U.S. rivals?
- Can we foresee how future rival leadership in this space could fundamentally undercut U.S. leadership and power?

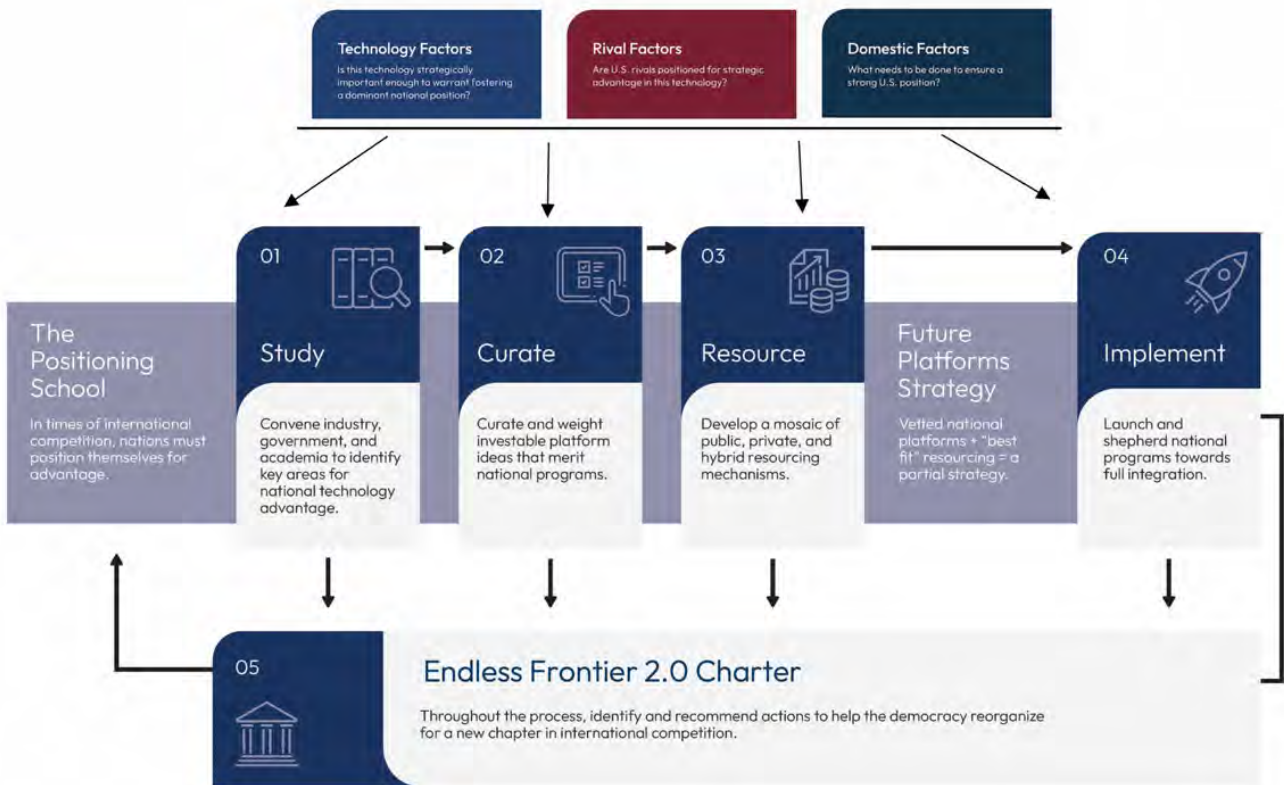
Domestic Factors

What needs to be done to ensure a strong U.S. position?

- Is the U.S. innovation ecosystem naturally generating sufficient advantage?
- Is there a clear U.S. competitive advantage surrounding this technology that needs a national endeavor to harvest?
- What is the maturity level of this technology? Would the U.S. need to "invent the future" to achieve positional advantage?
- Has the U.S. government listed this technology as a priority threat or opportunity area? What is the level of political or social will for this technology?
- Do allies and partners currently possess the key expertise and materials/resources in this technology?
- How might other countries respond to a U.S. national endeavor and are there obvious opportunities for joint efforts with allies?
- Which factors (incentives, financial, political, organizational, or regulatory) are currently limiting progress on this technology in the U.S.? Are these in the USG's control?

Altogether, this framework provides a method for sorting strategic signal from noise. A simpler method – or even relying on luck – may have sufficed in the past. Yet the rapid advance and convergence of technologies today and rivals’ techno-economic ambitions demand a more deliberate approach. Like other strategy methods, the framework is a flexible document. It can support multiple levels of analysis and stages in the strategy process.

At a macro level of analysis, the framework can help determine the sectors that a nation should focus on. This framework was used to develop a list of six general purpose technology battlegrounds that will drive global technology leadership in the 2025-2030 timeframe.¹²⁴ At a technology level of analysis, the framework can help recognize, generate, and refine bold technology objectives that would move the ecosystem towards a position of advantage. This level of analysis also helps identify the accompanying ecosystem levers that are necessary to achieve advantage. There is not a set number of framework criteria that a technology would need to meet in order to warrant national attention. Rather, the framework helps draw out a technology’s potential, the stakes of the competition, and the types of actions needed for advantage. The framework can support each stage of the strategy process. The technology and rival sections guide the key questions to ask during the “study” function. The domestic questions highlight the drivers, policy levers, and barriers that must be accounted for when curating, resourcing, and implementing Technology Action Plans.



¹²⁴ [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 172 (2022).

The Study Function: Building a National Horizon-Scanning Network

No singular organization is expressly charged with conducting horizon scanning for an America engaged in a techno-economic competition. In government, numerous entities scan the horizon to identify challenges that will affect their mission, but none is charged with comprehensively assessing the technology needs of the nation through a competitive lens.¹²⁵ Moreover, government horizon scanning functions lack a consistent plug-in for private sector actors who are at the bleeding edge of technology and in the trenches of competition with the rival.¹²⁶ A vast wealth of knowledge about technology and rival ecosystems remains untapped.

A horizon scanning function would compile voluntary insights from all corners of the U.S. innovation ecosystem. It would continuously track and assess the realm of the technologically possible, the key players in the innovation ecosystem, and potential technology gaps that could have profound impact on national security or national competitiveness. The organization itself could take many potential forms,¹²⁷ but its key output would be insights that inform strategic decisions about national technology moves.¹²⁸ In its first year, SCSP has developed an informal network of such horizon scanning entities. While this is an ongoing experiment, several lessons have surfaced that should inform such a future function:

Lessons from Horizon Scanning

Who is doing horizon scanning and why?

Many business, scientific, and academic insights into the direction of technology and the capabilities of rivals are often unrepresented in the Washington discourse. **Venture capital** firms regularly examine the technological frontier when looking for their next big investment or growth area.¹²⁹ **Banks** and **private equity firms** seek to inform the financial investments of their clients.¹³⁰ **Technology companies** and **consulting firms** scan for product development opportunities and future business verticals. **Universities** need to decide when to offer new courses and create new

¹²⁵ Amy Webb, [Why the Government Needs a Department of the Future](#), Politico (2016).

¹²⁶ While august in membership, the President's Council of Advisors on Science and Technology (PCAST) is the "the sole body of advisors from outside the federal government charged with making science, technology, and innovation policy recommendations to the President and the White House" and is quite small in number and limited in representation. [President's Council of Advisors on Science and Technology](#), The White House (last accessed 2022).

¹²⁷ For a discussion of technology strategy organizations, see the discussion in this report on "The Place: An Organizational Home for the Technology Strategy Process" at page 49.

¹²⁸ These insights would specifically inform government actors using the "strategic evaluation framework" previously described in this section to identify key technology sectors and national technology moves.

¹²⁹ See Sebastian Mallaby, [The Power Law: Venture Capital and the Making of the New Future](#), Penguin Press at 1-4 (2022) (discussing the example of a venture capital firm making a sizable bet on a geneticist for a venture that would become Impossible Foods).

¹³⁰ See [Horizon Scanning for New and Emerging Technologies in HealthTech](#), PwC (2018); [Horizon Scanning with Deutsche Bank](#), Deutsche Bank (2022).

departments. **Journalists** write annual technology “lists.”¹³¹ **Science fiction** authors and screenwriters build entire worlds around possible technology futures.¹³² **Foreign government** agencies convene horizon scanners to help their policymakers prioritize technology policies and investments.¹³³ Myriad other communities and organizations have formed around the intellectual exercise of studying technology trajectories, some offering their services for profit to help corporate leaders plan for the future.¹³⁴ While the methods and motives of these various entities differ, they search for the breakthroughs, tipping points, areas of convergence, and commercialization paths that will shape tomorrow’s technology landscape.

A number of private actors are also in the trenches of the geopolitical competition. Corporations have “political risk” shops – or contract with risk consultancies – to help them understand the geopolitical dimensions and directions of their business. Companies at the forefront of strategic technologies keep tabs on rivals’ progress and the relative strengths of each ecosystem.¹³⁵ Investors need to know which way the geopolitical winds are blowing to make smart bets.

Altogether, these actors possess vast insights on the innovation ecosystem. Some may have episodic information-sharing channels with specific governmental departments and agencies, such as consulting with the National Intelligence Council on its Global Trends reports.¹³⁶ However, nowhere are these insights stitched together to inform a national process.

Why would these actors join a national horizon scanning process?

Private sector horizon scanning efforts tend to revolve, understandably, around business opportunity. Yet when offered the opportunity, many are willing and even eager to think for the nation. Some who recognize the national security implications of trends on the horizon are yearning for a mechanism to share that information with the government. Organizations may also derive benefit from participating in such a network, which can help them identify their own blindspots, validate their work, and improve their understanding of government and other private actors’ priorities and perspectives. Furthermore, private actors operating at the technology frontier may want to bring those areas to the government’s attention to gain assistance in protecting against intellectual property (IP) theft or forced tech transfer, or to advocate for regulatory changes.

What is the structure or information-sharing mechanism for such a network?

¹³¹ See [10 Breakthrough Technologies 2022](#), MIT Technology Review (2022); [What Next? 22 Emerging Technologies to Watch in 2022](#), The Economist (2021).

¹³² See Arthur C. Clarke, [2001: A Space Odyssey](#), New American Library (1968); William Gibson, [Neuromancer](#), Ace (1986) (which coined the term “cyberspace”); Neal Stephenson, [Snow Crash](#), Bantam Books (1992) (which coined the term “metaverse”); August Cole & P. W. Singer, [Ghost Fleet: A Novel of the Next World War](#), Eamon Dolan/Houghton Mifflin Harcourt (2015); Alexandra Samuel, [Can Science Fiction Predict the Future of Technology](#), Jstor Daily (2019).

¹³³ See [The 11th Science and Technology Foresight](#), Japanese National Institute of Science and Technology Policy (2019); [Strategic Foresight Report 2022](#), European Commission (2022).

¹³⁴ See e.g., [Foresight Institute](#) (last accessed 2022); [Future Today Institute](#) (last accessed 2022).

¹³⁵ SCSP engagement with a leading biotechnology company (September 2022).

¹³⁶ [Global Trends 2040](#), U.S. Office of the Director of National Intelligence (2021).

Organizations will have different comfort levels in what they are willing to contribute to such a network, and with whom. In general, most are likely to be more willing to share their *insights* rather than the secret sauce of their *methods*. However, although some may be willing to share their insights with the network writ large, others may prefer to share solely with the entity convening the network.¹³⁷ Depending on the requirements of participating organizations, the network could be structured in a few ways:

- **Hub-and-spoke:** The technology strategy organization serves as a repository for insights. The “hub” could share a summary or abstraction of these insights with participant “spokes” in some mutually agreeable manner.
- **Interconnected:** The technology strategy organization serves as a forum for participating organizations to interact and exchange information with one another.
- **Hybrid:** The technology strategy organization serves both a repository and convening function for those participants who want to contribute to each.

In addition to a network of horizon scanners, what other tools or resources are available?

Numerous organizations regularly publish future technology trajectories, valuations, and trends. Reviewing, comparing, and aggregating these findings is an exercise that in itself provides significant insights into technology trends.¹³⁸ Additionally, the traditional sources of S&T information such as journal publications and patents remain a valuable resource when coupled with the proper analytical tools. For example, analyzing patents can offer insights into the rate at which certain technologies are maturing and help discern when technological breakthroughs, such as new battery technologies,¹³⁹ may reach an inflection point, and which quantum computing paradigms are maturing most rapidly.¹⁴⁰ Commercial databases that track the state of the startup ecosystem and venture capital investments can similarly provide useful insights into the trends of a key component of the modern innovation ecosystem.

¹³⁷ A horizon scanning organization that shared insights across participating organizations would require tailored information-sharing mechanisms to protect participating organizations’ tradecraft or intellectual property. One such model could be a series of periodical reports issued by the horizon scanning entity that contain key insights, but which are anonymized sufficiently so that the specific source of the information cannot be discerned.

¹³⁸ See for example SCSP’s exercise comparing 78 technology “lists” published by various organizations. [What’s In A Tech List?](#), SCSP 2-2-2 Newsletter (2022).

¹³⁹ Energy Report Part 1: Energy Storage, TechNext (2022) (*SCSP commissioned work product*); Computing Report, TechNext (2022) (*SCSP commissioned work product*).

¹⁴⁰ Anuraag Singh, et al., [Technological Improvement Rate Predictions for all Technologies: Use of Patent Data and an Extended Domain Description](#), Research Policy (2021).

The Curate Function: Developing Detailed Technology Goals and Plans for U.S. Advantage

The Curate Function moves the nation beyond listing key technologies into action planning to achieve advantage in them. Informed by the Study Function and the strategic evaluation framework, a national technology strategy entity must then curate Technology Action Plans that will position the nation for advantage.

The decision to curate can come from national leadership via a request for an action plan, through a recurring process that generates options for those leaders, or by an urgent need that becomes apparent from ecosystem indicators (e.g., 5G today). The curation process brings together key players across government, academia, industry, and civil society to help map the technology ecosystem,¹⁴¹ understand the gaps that exist, and identify the types of technology and policy interventions needed. This process helps identify the appropriate levers by which government, the private sector, and combined public-private elements of the ecosystem can drive advantage. There are four basic categories of how technology advantage plays out in the U.S. ecosystem.

- **Natural Commercial Advantage:** There are instances where the commercial market functions well on its own and national advantage emerges naturally. The **Internet platform landscape** is a durable form of U.S. sector advantage¹⁴² that arose through the efforts of the U.S. private sector.¹⁴³ Government must work with the private sector to ensure these existing advantages endure.
- **Government Catalyzes a Market:** Second, there are instances where a governmental nudge can catalyze and/or sustain a commercial market. Sometimes these nudges are targeted and decisive, like DARPA’s 2004 “grand challenge” on **autonomous driving** that spurred a wave of innovation in autonomous vehicles.¹⁴⁴ Other times, more substantial governmental engagement may be needed to motivate a market,¹⁴⁵ such as in **biomanufacturing**, where the government could help buy down the initial startup costs across a diverse set of actors and catalyze investment.¹⁴⁶
- **Government Creates the Market:** At the time of strategic decision, some technologies have no conceivable (or an extremely limited) commercial demand market. **Nuclear**

¹⁴¹ Steve Blank, [Mapping the Unknown – The Ten Steps to Map Any Industry](#), Steve Blank (2022).

¹⁴² For more on this, see the discussion of Internet Platforms/Social Media in Appendix B of this report.

¹⁴³ This was thanks in large part to the U.S. Government in the 1990s passing legislation supporting a fairly free, pro-commercial, and self-regulatory Internet. See e.g., Pub. L. 104-104, [Telecommunications Act of 1996](#) (1996).

¹⁴⁴ [The Grand Challenge](#), Defense Advanced Research Projects Agency (last accessed 2022).

¹⁴⁵ Technologies with high capital costs and long lead times are often referred to as “deep tech” or “tough tech.” See [Building a 21st-Century American Economy: The Role of Tough Tech in Ensuring Shared, Sustainable Prosperity](#), The Engine & Belfer Center for Science and International Affairs at 10 (2020); Massimo Portincaso, et al., [Deep Tech Ecosystems](#), Boston Consulting Group and Hello Tomorrow (2019).

¹⁴⁶ [The U.S. Bioeconomy: Charting a Course for a Resilient and Competitive Future](#), Schmidt Futures (2022).

weapons in the 20th century, and advanced weapons today like **hypersonics** would not have been developed without government-led development and procurement.¹⁴⁷ Similarly, the U.S. Government made up 100 percent of demand for integrated circuits (semiconductors) up to 1964, when a viable commercial market began to emerge.¹⁴⁸

- **Industry Teaches Government:** There are instances where the government is only made aware of *strategic applications* of an emerging technology platform by the private sector bringing it to its attention. In Ukraine, private companies like Amazon, SpaceX, and Microsoft have offered platforms such as **satellite internet services** and **virtual private networks (VPNs)** to solve logistics problems, keep Ukrainians online, and counter Russian censorship.¹⁴⁹ A public-private process can help the government more regularly identify platform opportunities that it may not see on its own.

The end result of the curation process should be a TAP containing a technical “minimum viable solution”¹⁵⁰ and an accompanying strategy for the surrounding ecosystem that together will ensure U.S. advantage. As discussed in the Plans section of this report, a TAP must at minimum address any questions of present infrastructure, supply chain resilience, relevant legal and regulatory regimes, available industry incentives, and necessary talent pipelines that are required to move the ecosystem in the right direction.¹⁵¹ Altogether, TAPs set a bold technical goal and clear a path in the ecosystem for success. Such plans leave no doubt as to who owns what and how the nation will achieve advantage. Yet a “minimum viable solution” is only a plan on paper until the required resources are marshaled to achieve it.

The Resource Function: Pooling Private Investor Logic and Interests

The Resource Function adds private sector logic into how to make technology advantage real. Marshaling those resources means putting money behind missions. With a new innovation geometry, new technologies, and a rival determined to win, the United States needs a new model to resource today’s needs and tomorrow’s opportunities.

¹⁴⁷ On historical nuclear weapons spending, see Stephen I. Schwartz, [Atomic Audit: The Costs and Consequences of U.S. Nuclear Weapons Since 1940](#), Brookings Institution Press (1998). On projected future nuclear weapons spending, see [Projected Costs of U.S. Nuclear Forces, 2021 to 2030](#), Congressional Budget Office (2021). On hypersonic weapons, see Kelley M. Saylor, [Hypersonic Weapons: Background and Issues for Congress](#), Congressional Research Service (2022).

¹⁴⁸ Chris Miller, [The Chip War](#), Scribner Press at 29-32 (2022).

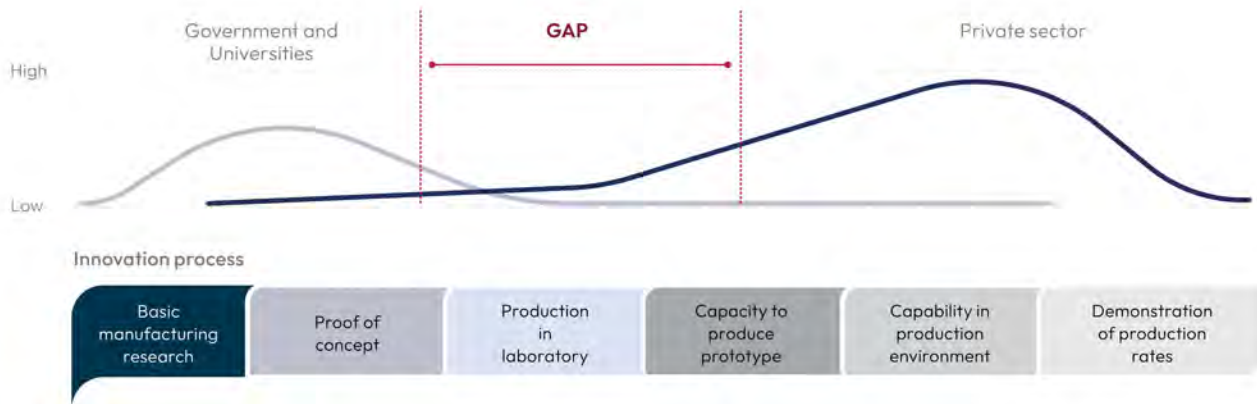
¹⁴⁹ Tom Simonite, [How Starlink Scrambled to Keep Ukraine Online](#), Wired (2022); [AWS-Powered App Helps Healthcare Workers Track Supplies in Ukraine](#), Amazon (2022); Brad Smith, [Defending Ukraine: Early Lessons from the Cyber War](#), Microsoft (2022); James Pearson & Christopher Bing, [Exclusive: U.S. Targets Russia with Tech to Evade Censorship of Ukraine News](#), Reuters (2022).

¹⁵⁰ “Minimum viable solution” is an adaptation of Steve Blank’s concept of a “minimal viable product.” See Steve Blank, [A Path to the Minimum Viable Product](#), Steve Blank (2021).

¹⁵¹ For fusion energy as an example TAP, see Appendix D of this report.

Innovators and investors are well aware of existing hurdles in the American innovation system. But to many, these barriers are hiding in plain sight.¹⁵² High upfront costs, technology risk, and certain regulatory hurdles can deter private investment in strategic technologies at key moments. Uncertainty on necessary accompanying innovations or infrastructure can chill investors or limit scale. Government research and development spending is primarily concentrated in basic research and development, leaving commercialization of that research under-supported. Outdated acquisition models can deny the U.S. Government access to leading technologies and an opportunity to provide a new market for emerging firms. Meanwhile, investors and start-ups are dependent on finding trusted capital in an increasingly murky market.¹⁵³ These dynamics combine together to yield funding gaps that create “valleys of death” where innovation perishes.¹⁵⁴

Funding Gap for Commercializing New Technologies¹⁵⁵



America must move quickly to overcome those obstacles. A national technology strategy process can take at least four steps to help reorient the U.S. innovation ecosystem:

1. Convene a Wide Range of Investors: Investing in cutting edge technologies requires, but can no longer be limited to, venture capital. A new public-private resourcing model must bring together different classes of investors ranging from venture capital and private equity to high net worth individuals and philanthropy. While the American financial ecosystem is highly networked, siloes remain. True cross-cutting convenings that span the full spectrum of investor types are rare. Such

¹⁵² For a discussion of the factors outlined in this paragraph, see [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 50-51 (2022).

¹⁵³ [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 51 (2022) (discussing trusted capital); Emily de La Bruyère & Nathan Picarsic, [The Weaponization of Capital: Strategic Implications of China’s Private Equity/Venture Capital Playbook](#), Foundation for the Defense of Democracies (2022).

¹⁵⁴ See Jonathan Gruber & Simon Johnson, [Jump-Starting America](#), Public Affairs at 98-103 (2019).

¹⁵⁵ GAO-21-202, [Department of Energy: Improved Performance Planning Could Strengthen Technology Transfer](#), U.S. Government Accountability Office (2021).

a convening – if regular and inclusive – would strengthen the U.S. innovation ecosystem, particularly around deep tech that requires consistent capital over a longer time horizon.¹⁵⁶ Introducing unfamiliar investors to deep tech and providing the expertise¹⁵⁷ needed to make informed decisions could expand the pool of potential deep tech capital.¹⁵⁸

2. Start at the Sector Level: In determining which particular investors to convene behind a Technology Action Plan, a technology strategy organization should begin its considerations at the sectoral level. The U.S. Government should not try to convene investors under an overly broad umbrella of tackling emerging or critical technologies. Technologies vary considerably in the financing hurdles they confront by sector. Some prospects may be clouded by regulatory uncertainty that chills private investors’ belief in returns on investment,¹⁵⁹ while others may reckon with high upfront capital costs that dissuade investors.¹⁶⁰ Thus, the type of action required, level of private sector interest, and specific role that the U.S. Government could play can be quite distinct. Painting with a broad brush would miss that nuance. Once the proper sector is identified, the technology readiness level (TRL)¹⁶¹ identified during the Curation Phase can be a further indicator of an even more precise group of investors to bring to bear on a technology goal.

¹⁵⁶ [Building a 21st-Century American Economy: The Role of Tough Tech in Ensuring Shared, Sustainable Prosperity](#), The Engine & Belfer Center for Science and International Affairs at 10 (2020); Josh Lerner & Ramana Nanda, [Venture Capital’s Role in Financing Innovation: What We Know and How Much We Still Need to Learn](#), Harvard Business School Working Paper 20-131 at 7-10 (2020).

¹⁵⁷ Massimo Portincaso, et al., [The Deep Tech Investment Paradox: A Call to Redesign the Investor Model](#), Boston Consulting Group and Hello Tomorrow at 23 (2021) (“[D]eep tech suffers from a lack of information and communication.”). Furthermore, venture capital firms are the largest players in the deep tech investment space, but reflect only a small segment of the American financial market. Josh Lerner & Ramana Nanda, [Venture Capital’s Role in Financing Innovation: What We Know and How Much We Still Need to Learn](#), Harvard Business School Working Paper 20-131 at 7 (2020).

¹⁵⁸ The alternative would be investors choosing to build their own independent expertise. See Massimo Portincaso, et al., [The Deep Tech Investment Paradox: A Call to Redesign the Investor Model](#), Boston Consulting Group and Hello Tomorrow at 30-31 (2021). A degree of information sharing would not be alien to the collaborative VC ecosystem. VC firms look for partners in funding rounds. Prospective investment partners need access to quality data to make their decisions. A forum providing access to science and technology experts from multiple specialized VC firms – or independent assessors – to corroborate would heighten trust and smooth the path for investment. See [How Often Do VCs Collaborate With Each Other? The Data Tells The Tale](#), Kauffman Fellows (2018); Christian Hoop, [When Do Venture Capitalists Collaborate? Evidence on the Driving Forces of Venture Capital Syndication](#), Small Business Economics (2009). This is not to say that VC dynamics are *always* cooperative. See Paul Gompers, et al., [How Venture Capitalists Make Decisions](#), Harvard Business Review (noting VC firms “can be very aggressive when they spot a company they like.”).

¹⁵⁹ See [The Challenges of ‘Tough Tech’: The American Venture System and National Competitiveness](#), Private Capital Research Institute and the Private Capital Project at Harvard Business School at 3 (2022); For a specific example in “air taxis,” see Joann Muller, [Flying Taxis Get a Big Boost from Military Money](#), Axios (2022); Bernd Debusmann, [You May Be Able to Book a Flying Taxi Within Three Years](#), BBC (2021).

¹⁶⁰ See Jonathan Gruber & Simon Johnson, [Jump-Starting America](#), Public Affairs at 101 (2019).

¹⁶¹ A technology readiness level is a scale used by the U.S. Government and other actors to measure a technology’s maturity. See [Technology Readiness Assessment Guide](#), U.S. Department of Energy at 1-3 (2011). The scale runs from TRL 1, where “[b]asic principles [are] observed and reported,” to TRL 9, where “[a]ctual system . . . [is] proven through successful mission operations.” [Technology Readiness Level Definitions](#), U.S. National Aeronautics and Space Administration (last accessed 2022).

Knowing the correct TRL can also guide policymakers in identifying the most appropriate policy levers to deploy to remove obstacles to investors and open new doors.

3. Foster Wider, Systematic Information Sharing: A technology strategy organization should facilitate more systemic information sharing between the government and private sector, among domestic private sector actors, and between the U.S. ecosystem and those of allies and partners. Such a mechanism can help bring new opportunities to the attention of unaware funders,¹⁶² expand their knowledge on specialized technology areas,¹⁶³ identify breaks in funding chains,¹⁶⁴ and provide an opportunity to articulate to government persistent funding gaps that the private sector will not fill.

4. Drive Select Moonshots: Technology moonshots will remain a key driver of positional advantage, even with a national technology strategy process. America is primed for this, and investors can help. There are multiple models for government and the private sector to team up on moonshots. As with the original moonshot, the U.S. Government can partner with private companies, setting the mission goals, parameters, and timelines.¹⁶⁵ Private sector actors then would be accountable to those goals. Alternatively, the U.S. Government can harness the often competitive nature of innovators and investors by incentivizing private sector activity in a space through grand challenges.¹⁶⁶

A Wealth of New Partners

A technology strategy organization has a wealth of new partners to engage in pursuing technology objectives. A new generation of entrepreneurship trainers and venture firms, both American and international, are filling gaps in the ecosystem. For instance, a growing number of academic opportunities are starting to train the

¹⁶² E.g. Massimo Portincaso, et al., [The Deep Tech Investment Paradox: A Call to Redesign the Investor Model](#), Boston Consulting Group and Hello Tomorrow at 4 (2021) (“Deep tech remains outside the risk profile and deal flow of most [private equity] funds”). Not all private sector firms possess horizon scanning capabilities; however some companies offer such services.

¹⁶³ Some of that information sharing can occur in the Study Function, if horizon scanners from private entities are regularly participating.

¹⁶⁴ Massimo Portincaso, et al., [The Deep Tech Investment Paradox: A Call to Redesign the Investor Model](#), Boston Consulting Group and Hello Tomorrow at 43 (2021) (discussing how private equity could pick up the thread at certain scaling points).

¹⁶⁵ NASA, for example, has continued this structure of public and private entities working together to this day. See Tim Fernholz, [NASA Has Always Needed Private Companies to Go to the Moon](#), Quartz (2021).

¹⁶⁶ See e.g., [U.S. and U.K. Launch Innovation Prize Challenges in Privacy-Enhancing Technologies to Tackle Financial Crime and Public Health Emergencies](#), The White House (2022); [The DARPA Grand Challenge: Ten Years Later](#), Defense Advanced Research Projects Agency (2014).

next generation of national security-oriented innovators and entrepreneurs.¹⁶⁷ Simultaneously, a new class of deep tech-specific VC firms are blazing a trail that offers lessons for other existing or new investors and could be scaled to other U.S. cities.¹⁶⁸ Additionally, space is rapidly growing for innovation investment collaboration with key American allies and partners via initiatives like the United Kingdom’s Advanced Research and Invention Agency (ARIA),¹⁶⁹ NATO’s Defence Innovation Accelerator for the North Atlantic (DIANA),¹⁷⁰ and the Joint European Disruptive Initiative (JEDI).¹⁷¹

The Implement Function: Overseeing and Supporting Implementation of Plans Across Administrations

The Implement Function is active oversight and measurement of intended achievements long-term – including across administrations and congresses. There are three core competition factors demanding fresh oversight of national technology action plans.

- **Accountable Plan Leadership.** First, ambitious technology programs are by their nature hard and not every leader can deliver them. Enacting real change requires naming and empowering hand-selected individuals to be squarely responsible for delivering big technology moves. In large technology programs that potentially span more than one government agency, it is essential to have one person accountable for the results. That leader must have authority to oversee and move actors while also clearly and regularly reporting on progress to elected leaders.
- **Institutional Continuity.** Second, considering authoritarian rivals, long-term continuity between administrations is a U.S. Achilles heel in a sprawling multi-sector technology competition. A single-party system like the CCP has irrationalities but it does provide continuity. In a democracy, continuity comes from institutions and laws that remain when elected officials cycle in and out of government. This means the PRC could simply out-organize the United States unless the nation accounts for the natural and virtuous churning of democracy. Sustained attention, strategy, study, planning, and oversight would increase overall U.S. competitiveness.

¹⁶⁷ One particularly effective model is Hacking for Defense, which has run in 44 American universities. See [Universities](#), Hacking for Defense (last visited 2022); Mark Sullivan, [In This Popular Stanford Class, Students Build Tech for the Military](#), Fast Company (2021).

¹⁶⁸ The Engine represents one such tough tech organization that is active and willing to share its lessons. See [Our Mission](#), The Engine (last visited 2022); [Building a 21st-Century American Economy: The Role of Tough Tech in Ensuring Shared, Sustainable Prosperity](#), The Engine & Belfer Center for Science and International Affairs (2020). See Massimo Portincaso, et al., [The Deep Tech Investment Paradox: A Call to Redesign the Investor Model](#), Boston Consulting Group and Hello Tomorrow at 4-5 (2021).

¹⁶⁹ [Advanced Research and Invention Agency \(ARIA\): Policy Statement](#), UK Department for Business, Energy & Industrial Strategy (2021).

¹⁷⁰ [NATO Sharpens Technological Edge with Innovation Initiatives](#), North Atlantic Treaty Organization (2022).

¹⁷¹ [The European ARPA](#), Joint European Disruptive Initiative (last accessed 2022).

- **Dedicated Organization.** Third, as a domestic dynamic, active oversight of national action plans is critical because most relevant competitions lack a single department or agency to see advantage through to final success the way NASA carried the Apollo Program or the U.S. Armed Forces carried The Manhattan Project. For example, there is no single computer science-focused agency to carry the artificial intelligence competition. The Department of Health and Human Services is not inherently a national security organization empowered to map biotechnology dominance as a routine strategy behavior. There is no single department or agency to coordinate and align networks like the Manufacturing USA institutes¹⁷² around the goal of integrating converging general purpose technologies into “Factories of the Future” all across America. There is no longer a U.S. Information Agency¹⁷³ to treat the information environment as a domain unto itself. A national competition process begs for implementation oversight particularly for technologies that cross multiple departments and agencies or have no clear government owner/leader.

The following questions outline implementation basics that should also be considered when assessing technology action plans:

- *Is there a single leader of the national technology plan or program and can they do it?*
- *Are the right actors across the private and public sectors involved?*
- *Is the action plan or program sufficiently resourced?*
- *Is there a sufficiently ambitious timeline to achieve the positional advantage?*
- *Is there a minimum-essential reporting process in place to account to the President or Congress on the progress?*

If the answer to those questions are “yes”, the implementation function of the national competition process is likely on track for the technology in question.

The Organize Function: Learning from Each Step How to Craft an Endless Frontier 2.0 Charter

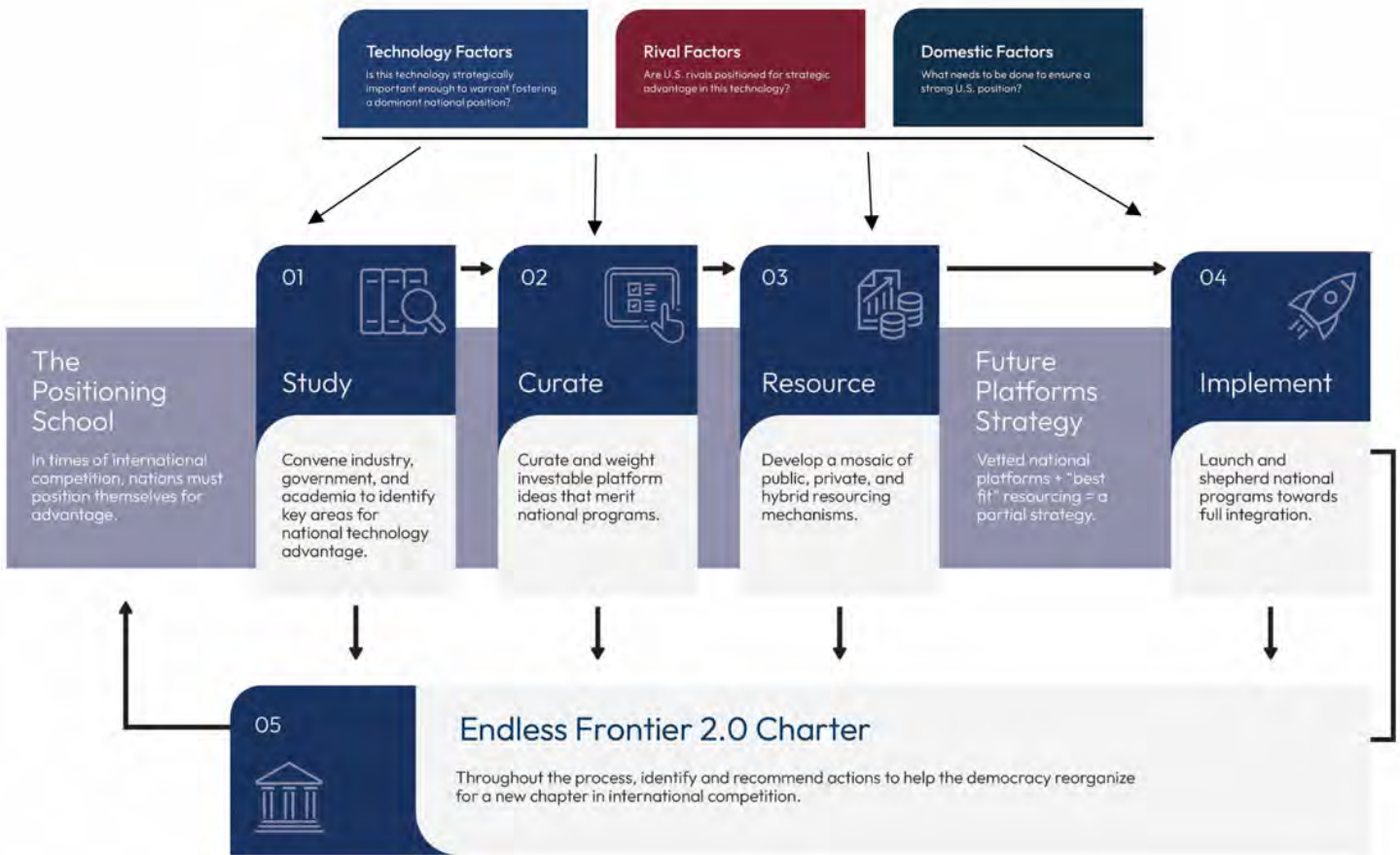
The Organize Function is about continuous learning of the structural adjustments needed to support the U.S. innovation ecosystem as discovered throughout the process. As depicted in the National Technology Strategy Process graphic on the following page, continuous engagement with thought leaders across the private innovation ecosystem cannot help but generate insights into how the nation could be better postured to compete. Foundational to this would be forging a charter for an Endless Frontier 2.0, which would modernize Dr. Vannevar Bush’s framework¹⁷⁴

¹⁷² See John F. Sargent Jr., [Manufacturing USA: Advanced Manufacturing Institutes and Network](#), Congressional Research Service (2022).

¹⁷³ See Hal Brands, [The Twilight Struggle](#), Yale University Press at 186–88 (2022).

¹⁷⁴ See Vannevar Bush, [The Endless Frontier - 75th Anniversary Edition](#), National Science Foundation (2020).

and build on the work of Congress in the CHIPS and Science Act.¹⁷⁵ This work involves drafting a complete vision to make the new U.S. innovation ecosystem whole.



Combining Economic Factors: A Complete Competition Model

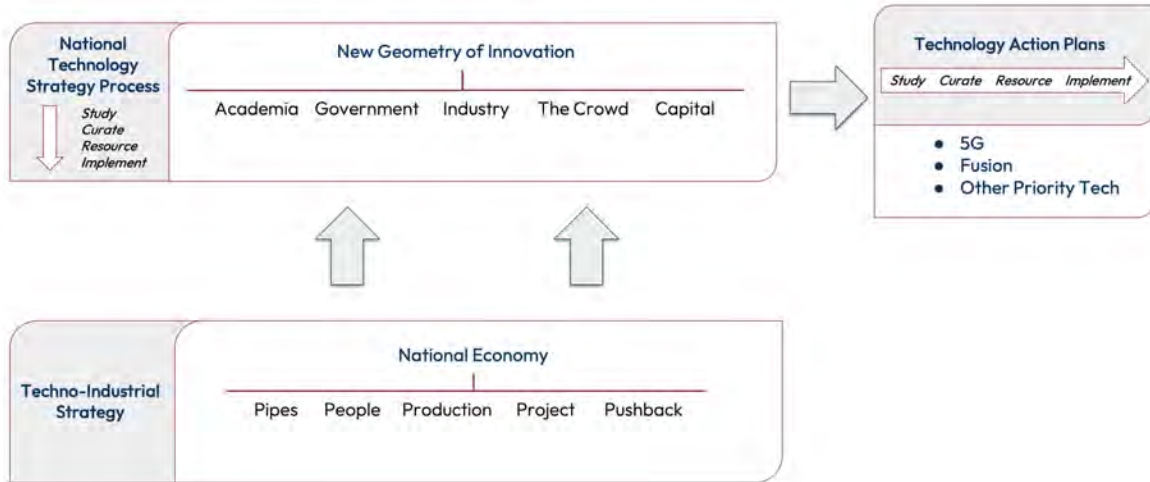
If the national public-private model were in place, how would it fit with economic factors? At times, a national process must be combined with selective industrial strategy to provide the nation with economic inputs needed in the innovation ecosystem. Competing requires the United States to not only more actively steward scientific innovation, but also take a more proactive approach to the economic pillars that underlie the innovation ecosystem. The current approach, where the U.S. Government largely has left science and its economic inputs and outcomes to arise naturally, has produced gaps in U.S. capabilities that leave the country vulnerable and playing catch-up.¹⁷⁶

¹⁷⁵ U.S. Senators Chuck Schumer and Todd Young and Representatives Ro Khanna and Mike Gallagher introduced a bipartisan, bicameral Endless Frontier Act in 2020 that inspired science and technology provisions found in the CHIPS and Science Act (Pub. L. 117-167).

¹⁷⁶ Eric Schmidt & Yll Bajraktari, [America Could Lose the Tech Contest With China](#), Foreign Affairs (2022).

Pivoting from a reactionary to a more proactive footing involves two complementary components. First is the **national technology strategy process** that successfully leverages the new geometry of innovation to generate specific technological advances. This strategy sits atop and relies upon the second component, an American **techno-industrial strategy (TIS)** that ensures the United States possesses a strong foundation of economic inputs and policies.

A National Model for Technology Advantage



Through a selective TIS, the government would make targeted interventions to ensure the innovation actors have the required inputs in key sectors – partnering with the private sector to unleash a new wave of innovation and boosting growth by clearing the runway for emerging technologies to diffuse across the economy.¹⁷⁷

The TIS provides the economic foundations for a national technology strategy process that generates action plans identifying specific policy, regulatory, and technology moves that would drive progress in a specific technology field. Often these TAPs will overlap with aspects of a techno-industrial strategy. Indeed, the process of generating TAPs will identify needs and gaps in the ecosystem that inform revisions to the techno-industrial strategy. For example, a TAP for 5G is fundamentally about improving the infrastructure “pipes” that underpin long-term U.S. economic competitiveness and would thus be a key element of a strategy for U.S. digital infrastructure.

The combination of the U.S. innovation ecosystem and the U.S. economic ecosystem comprise billions of interactions that cannot be centrally directed. Yet once the nation chooses to compete in a technology, a complete National Technology Action Plan will involve elements of both. The

¹⁷⁷ For more on Techno-Industrial Strategy, see [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project (2022).

national PPP for technology competition is the minimum process that intersects with the innovation ecosystem. Techno-industrial strategy is the minimum process that intersects with the economy itself to ensure innovators have the inputs they need to succeed. National action plans would be based on two levels of analysis. On the tech level, experts from around the country would routinely and systematically contribute to this PPP for a technology strategy process. Private sector actors would help to shape bold technology objectives required to keep the United States ahead and the technology-level of mapping needed to get there. On the policy level, a solid plan should incorporate economic, policy, and – if necessary – legislative moves to achieve national advantage. This policy level of planning would include industrial strategy variables as required, drawing from the pillars of the strategy: production, pipes, people, project, and pushback.¹⁷⁸ The complete competition model – a public-private process that creates TAPs including economic inputs from selective industrial strategy – begs the question of where this public-private partnership can come together.

The Place: An Organizational Home for the Technology Strategy Process

America needs an institutional home for the national technology strategy process to gather the innovation ecosystem’s potential. The United States has long embraced new organizational arrangements to meet international challenges.¹⁷⁹ Given the techno-economic competition’s stakes, the question is approached *tabula rasa*. Why America’s current institutions fell behind is knowable; therefore, so are the necessary elements for a technology strategy entity to close those gaps. There are eight such elements: (1) access to senior public leaders; (2) the capacity to routinely engage private sector leaders; (3) a competitive lens; (4) a broad technology scope; (5) independence in analysis; (6) an accountable action arm; (7) longevity and continuity; and (8) signaling priority to the government and public.

That rubric enabled consideration of four potential models for action: (1) reforms to existing institutions; (2) a new Technology Competitiveness Council (TCC) supplemented by an Office for Global Competition Analysis (OCA);¹⁸⁰ (3) a federally-chartered non-profit organization, a U.S.

¹⁷⁸ See [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project at 3 (2022).

¹⁷⁹ For examples from the National Security Council to the War Industries Board, see Hal Brands, [The Twilight Struggle](#), Yale University Press at 174-78 (2022); [Mobilizing America's Economy and Society](#), U.S. World War I Centennial Commission (last accessed 2022).

¹⁸⁰ In 2022, Congress considered legislation for both a Technology Competitiveness Council (TCC) and Office of Global Competition Analysis (OCA). H.R. 8027, [To Establish within the Executive Office of the President a Technology Competitiveness Council](#) (2022); Courtney Albon, [Lawmakers Propose 'Technology Competitiveness Council' to Champion US Innovation](#), C4ISRNet (2022); S. 4368, [American Technology Leadership Act of 2022](#) (2022); Daniel Flatley, [Senators Wary of China's Tech Prowess Seek Competition Office](#), Bloomberg (2022). The NSCAI recommended creating a TCC in its final report in 2021. [Final Report](#), National Security Commission on Artificial Intelligence at 166 (2021).

Advanced Technology Forum (USATF); and (4) an independent, privately funded technology organization.¹⁸¹

Grading Four Models to Organize

	Model 1: Reform Existing Institutions	Model 2: Joint TCC-OCA	Model 3: U.S. Advanced Technology Forum	Model 4: Independent Private Organization
Access to Public Leaders				
Capacity to Routinely Engage Private Sector Leaders				
Competitive Lens				
Broad Technology Scope				
Independence in Analysis				
Accountable Action Arm				
Longevity and Continuity				
Signal Priority				

	High Efficacy		Moderate Efficacy		Low Efficacy
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¹⁸¹ For an evaluation of each of these four models as assessed against the eight identified elements, see Appendix C of this report.

While no model is perfect, **a hybrid approach that unites the second and third options** would best serve the United States in the techno-economic competition. A TCC would serve as a central White House-based action arm. An OCA would provide a consistent analytic center across administrations. Finally, the parallel federally-chartered non-profit, USATF, would offer a more open, lasting forum for analysis and convenings necessary for the competition.

A Hybrid Organizational Model



How to Get Ahead: Elements for Success

Looking forward, a fundamental review is in order. An ideal technology strategy organization should incorporate eight elements to best position America to compete:

- 1. Access to Senior Public Leaders:** The ideal entity would have direct access to senior government leaders to inform their decision-making, receive guidance for its own strategic choices, and enhance credibility in convening public and private actors.
- 2. Capacity to Routinely Engage Private Sector Leaders:** The ideal entity would regularly engage with a range of private sector stakeholders to gather data for analysis, inform its strategic choices, and coordinate public-private action on technology objectives.

3. *A Competitive Lens*: The ideal entity would conduct its work via the lens of winning the techno-economic competition. That extends beyond narrow national security conceptions to technology’s impacts on America’s economy, governance capacity, and civil society.
4. *Broad Technology Scope*: The ideal entity would be responsible for and operate across a range of technology sectors, as there are at least six key technology battlegrounds on the horizon and technology itself continues to rapidly evolve.¹⁸²
5. *Independence in Analysis*: The ideal entity would conduct independent horizon scanning to identify and assess technology trends. While the entity would be open to requests for specific analysis, it would largely drive itself to ensure objectivity.¹⁸³
6. *Accountable Action Arm*: The ideal entity would drive public-private action on identified technology objectives. A clear “national mission manager” empowered with the appropriate authorities would be able to hold the U.S. bureaucracy to account and be accountable to senior policy leaders.
7. *Longevity and Continuity*: The ideal entity would possess longevity, persisting as an institution across administrations. It also would possess some continuity in personnel in order to retain institutional memory and consistently pursue long-term objectives.
8. *Signal Priority*: The ideal entity’s creation and continued access to senior leaders would signal to the U.S. Government, private sector, and general public the importance and seriousness that America’s leaders ascribe to the techno-economic competition.

No organization should be expected to excel in all eight elements. Some elements contain internal tensions that must be balanced, making assessments of each element more spectrum-based than binary in nature. Nevertheless, the entity that most optimizes these elements would best carry out the national technology strategy process.

Status Quo is Not Sufficient

Based on the preceding elements, America’s existing institutions, as currently configured, do not meet the competition needs. Reviewing three¹⁸⁴ extant institutions – the NSC; OSTP; and the NSTC

¹⁸² See [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 170-181 (2022).

¹⁸³ Erica Fuchs, [Building the Analytical Capacity to Support Critical Technology Strategy](#), Brookings: The Hamilton Project at 10-11 (2022) (on the importance of independence in analysis on technology trends).

¹⁸⁴ While PCAST reflects a fourth institution, it lacks any form of action arm necessary here for full consideration. John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 16 (2020) (noting PCAST is an advisory body). See generally [Report to the President: Revitalizing](#)

– each performs critical work, and often under trying conditions. Nevertheless, none of these institutions is optimized to meet the elements of an ideal technology strategy organization.¹⁸⁵

- *The National Security Council:* The NSC sits at the center of the country’s national security architecture. It efficiently carries out the weighty task of coordinating the country’s globe-spanning national security policy. However, as currently arranged, the NSC would be challenged to fulfill the elements for a long-term technology strategy organization. While the NSC has almost unparalleled access to senior government leaders, an intent to avoid any perception of unequal access or favoritism can disincentivize routine private sector engagement. That same leadership access can also crowd out long-range strategy work.¹⁸⁶ The NSC would be unlikely to create a dedicated horizon scanning office of sufficient scope, particularly because it would require moving beyond the traditional national security perspective. The NSC would need to expand to areas beyond its existing remit to achieve the necessary competitive lens.¹⁸⁷ Finally, the churn of NSC staff would undercut personnel continuity¹⁸⁸ while presidential discretion to adjust NSC composition could change the mandate at any time.¹⁸⁹
- *The Office of Science and Technology Policy:* OSTP is the premier entity for advising the President on science and technology policy. The Office also is charged with coordinating a wide range of federal departments and agencies’ science and technology activities. However, OSTP is not positioned to operate under a competitive lens.¹⁹⁰ It neither sets nor drives geopolitical strategy, particularly as it plays out in specific geographic regions. Its national security work is largely siloed,¹⁹¹ and most critical national security work is managed outside of OSTP by the NSC. Refocusing OSTP primarily on the competition

[the U.S. Semiconductor Ecosystem](#), Executive Office of the President, President’s Council of Advisors on Science and Technology (2022).

¹⁸⁵ The issues outlined in this section are structural in their very nature. This analysis does not impugn the crucial efforts of the individuals, often at considerable sacrifice to themselves and their families, who work in these institutions. The combined staff of appointees, civilians, and detailees reflect the highest values and caliber of public service.

¹⁸⁶ Stephen Hadley, [Reforming the National Security Council: Policy Prescriptions and Recommendations](#), Aspen Institute at 108-09 (2016) (paper within America’s National Security Architecture); Julianne Smith, [Reforming the National Security Council: Three Questions for the Next President](#), Aspen Institute at 104-05 (2016) (paper within America’s National Security Architecture).

¹⁸⁷ See Loren DeJonge Schulman & Ainikki Riikonen, [Trust the Process: National Technology Strategy Development, Implementation, and Monitoring and Evaluation](#), Center for a New American Security at 10 (2021).

¹⁸⁸ John Rollins, [The National Security Council: Background and Issues for Congress](#), Congressional Research Service at 7-8 (2022).

¹⁸⁹ See Brendan McCord & Zoe Weinberg, [Emerging Technology & The Future of the National Security Council](#), Stanford University Center for International Security and Cooperation at 15 (2020); David Rothkopf, [Running the World](#), Public Affairs at 5-6 (2004).

¹⁹⁰ Robert Atkinson, [How to Win the U.S.-China Economic War](#), Foreign Policy (2022) (discussing the challenge of a “narrow” strategic lens).

¹⁹¹ John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 5 (2020); Henry Kelly, et al., [Flying Blind: The Rise, Fall, and Possible Resurrection of Science Policy Advice in the United States](#), Federation of American Scientists at 30 (2004).

would deprive the President of other necessary science and technology perspectives. While OSTP could outsource regular horizon scanning to the Institute for Defense Analysis' Science and Technology Policy Institute (STPI), STPI is relatively small; it would require a sizable funding increase and new competitive lens to perform that role to the fullest.¹⁹² Likewise in strategic planning, OSTP has often, but not exclusively, focused its strategies “on narrow topics,” not wider conceptions of national competitiveness.¹⁹³ Nor does OSTP wield sufficient command in the interagency process to serve as an accountable action arm. OSTP is perceived “more as a technical advisor than [a] strategic lead.”¹⁹⁴ Intermittent access to the President can further undercut its stature.¹⁹⁵ Lastly, while OSTP's statutory basis provides institutional longevity, it generally lacks personnel continuity, though STPI could help fill that continuity gap.¹⁹⁶

- *The National Science and Technology Council:* As currently organized, the NSTC would likely struggle to fulfill the role needed for the techno-economic competition. Like OSTP, the NSTC's approach to national security is siloed and its conception of competitiveness is insufficiently holistic.¹⁹⁷ Additionally, the NSTC lacks access to the President and bureaucratic muscle on par with that of the NSC.¹⁹⁸ Owing its existence to executive order, the NSTC lacks institutional longevity¹⁹⁹ and its staff largely turns over with administrations.²⁰⁰ Finally, given the NSTC's low visibility and name recognition, it seems unlikely to galvanize the nation to action. Lesser known organizations can become

¹⁹²As of 2020, STPI possessed only 40 full-time staff and a budget of \$4.74 million. John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 9, 23 (2020).

¹⁹³ Matt Hourihan, [CHIPS and Science Highlights: National Strategy](#), Federation of American Scientists (2022). That is not to say that OSTP, in conjunction with the NSTC, has not intermittently produced reports on strategic sectors. See [National Strategy for Advanced Manufacturing, Subcommittee on Advanced Manufacturing](#), U.S. National Science and Technology Council (2022); [Preparing for the Future of Artificial Intelligence, Committee on Technology](#), U.S. National Science and Technology Council (2016).

¹⁹⁴ Loren DeJonge Schulman & Ainikki Riikonen, [Trust the Process: National Technology Strategy Development, Implementation, and Monitoring and Evaluation](#), Center for a New American Security at 10 (2021).

¹⁹⁵ Henry Kelly, et al., [Flying Blind: The Rise, Fall, and Possible Resurrection of Science Policy Advice in the United States](#), Federation of American Scientists at 30 (2004).

¹⁹⁶ Henry Kelly, et al., [Flying Blind: The Rise, Fall, and Possible Resurrection of Science Policy Advice in the United States](#), Federation of American Scientists at 35 (2004).

¹⁹⁷ See John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 12-13 (2020). Since the 2007 America COMPETES Act, the NSTC has held a mandate to consider national competitiveness and yet the U.S. science and technology apparatus still did not mobilize around the techno-authoritarian threat. John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 12-13 (2020); Pub. L. 110-69, [America COMPETES Act](#) (2007).

¹⁹⁸ John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 12 (2020); Henry Kelly, et al., [Flying Blind: The Rise, Fall, and Possible Resurrection of Science Policy Advice in the United States](#), Federation of American Scientists at 31-32 (2004).

¹⁹⁹ E.O. 12881, [Establishment of the National Science and Technology Council](#), The White House (1993).

²⁰⁰ John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 13 (2020).

household names when given the proper remit and authority.²⁰¹ However, here a relatively unknown entity would need to surge to new importance and punch far above its weight in a crowded organizational field.

A Hybrid Model for Action

Two proposed initiatives could combine to provide the United States with technology strategy continuity between administrations. The Technology Competitiveness Council was recommended by the NSCAI as a White House-based action arm for conducting technology strategy.²⁰² The Office of Global Competition Analysis is a recent congressional proposal²⁰³ for an analytic office to perform comparative analysis on international technology dynamics. A joint TCC-OCA model, combining both action and intellectual continuity, stands out as the leader among four surveyed options²⁰⁴ for a technology strategy entity along the eight identified criteria.

One additional step could even further strengthen America's ability to compete. Pairing the TCC-OCA model with a parallel U.S. Advanced Technology Forum (analyzed in full in Appendix C) would yield a mutually reinforcing constellation of actors.

- *The Core: Technology Competitiveness Council & Office of Global Competition Analysis*

Enacting the joint proposals of an OCA and a TCC could create a tandem set of institutions. The OCA would sit outside the White House as a hub for conducting long-term technology analysis. Removed from direct political considerations and the crush of the urgent, the OCA could draw on government and voluntarily-shared private data in horizon scanning for strategic technologies.

Simultaneously, a White House-based TCC would serve as an action arm for implementing technology strategy. Either the Vice President or a new Assistant to the President for Technology Competition would oversee the TCC staff and manage the national technology strategy process. That senior champion would help ensure the TCC would not be sidelined amidst the scrum of the policymaking process. The TCC staff would draft TAPs for OCA-identified strategic technologies. They also would oversee the appointment of national mission managers and convene public and private investors for alignment working groups to support robust capital stacks that see a technology through from early stages to wide dissemination.

Assessed along the eight elements, the TCC-OCA combination is a highly effective model. The TCC's White House location would allow it *access to senior public leaders*. Those direct ties would enhance the TCC's credibility with the private sector as representing the President's priorities,

²⁰¹ See e.g., Charles Murray & Catherine Bly Cox, [Apollo: The Race to the Moon](#), Simon and Schuster at 23-25 (1989) (discussing the early transformation of the National Advisory Committee for Aeronautics (N.A.C.A.) into NASA).

²⁰² [Final Report](#), National Security Commission on Artificial Intelligence at 166 (2021).

²⁰³ See S. 4368, [American Technology Leadership Act of 2022](#) (2022); Daniel Flatley, [Senators Wary of China's Tech Prowess Seek Competition Office](#), Bloomberg (2022).

²⁰⁴ For full methodology and analysis of options, see Appendix C of this report.

supporting its *capacity to routinely engage private sector leaders*. Furthermore, the pairing with the OCA would provide an additional plug-in point for private sector actors. That second space for dialogue allows for more granular discussions of technology trends in a setting removed from political winds and the influence of more immediate priorities.²⁰⁵

Likewise, the TCC-OCA combination would be able to adopt the necessary *competitive lens* and *broad technology scope* from the outset. By not having to adapt an existing institution's remit and organizational culture, there would be few barriers to acting under this new mandate. Placing that mission outside the NSC and OSTP also would avoid diluting the valuable perspectives of those existing offices and prevent over-securitization of the TCC-OCA's work.²⁰⁶

The OCA also would provide capacity for *independence in analysis* when conducting long-term horizon scanning. The OCA could couple a permanent analytical staff with rotating nongovernmental fellows to enhance information flows within government and between the public and private sectors.²⁰⁷ The TCC then would be responsible as the *accountable action arm* for those identified technologies. The TCC would run a rigorous interagency process, leveraging the weight of the White House to support national mission managers leading action on TAPs.²⁰⁸

If enacted by Congress, the TCC-OCA model would offer *longevity and continuity* in operations. A statutory foundation would best ensure the dual institutions lasted over time, though the reality remains that Presidents have considerable discretion in managing White House offices.²⁰⁹ Simultaneously, by placing the OCA outside the White House, potentially as a new FFRDC, it would be positioned to retain personnel over a longer time horizon in service of long-term missions. Finally, establishing a joint TCC-OCA would *signal priority* ascribed to the competition. The TCC-OCA duo would have to assert itself in a crowded field. Nonetheless, its creation would show multiple branches of government acting together on the competition.

²⁰⁵ Erica Fuchs, [Building the Analytical Capacity to Support Critical Technology Strategy](#), Brookings: The Hamilton Project at 10-11 (2022) (discussing the importance of independence in analysis); [Remarks by Erica Fuchs at Reimagining Industrial Policy for the Service and Tech Sectors](#), Brookings Institution at 1 hour, 9 (2022).

²⁰⁶ Erica Fuchs, [What a National Technology Strategy Is – and Why the United States Needs One](#), Issues in Science and Technology (2021); Brendan McCord & Zoe Weinberg, [Emerging Technology & The Future of the National Security Council](#) at 24 (2020).

²⁰⁷ See Erica Fuchs, [Building the Analytical Capacity to Support Critical Technology Strategy](#), Brookings: The Hamilton Project at 10-11 (2022).

²⁰⁸ Henry Kelly, et al., [Flying Blind: The Rise, Fall, and Possible Resurrection of Science Policy Advice in the United States](#), Federation of American Scientists at 32 (2004) (noting a lack of such a rigorous process at the highest level of science and technology policy).

²⁰⁹ As an example, despite being established by law in 1989, the National Space Council was not operational from 1993 to 2017. [National Space Council](#), The White House (last accessed 2022).

- *Filling the Gaps: U.S. Advanced Technology Forum*

While the TCC-OCA combination ranks well on the eight elements, it possesses some weaknesses. Private actors may be reluctant to share information directly with the government.²¹⁰ A compact White House-based staff would have limited bandwidth to engage with a wide range of investors. Consequently, supplementing the TCC-OCA model with a Congressionally-established independent nonprofit corporation — the U.S. Advanced Technology Forum — would bolster the TCC-OCA to provide greatest effectiveness.

Congress could establish USATF as an independent institution, but define its mission and oversee its action by appointing a bipartisan board of directors.²¹¹ USATF would be positioned to conduct its own horizon scanning, collaborating with industry and academia with fewer concerns around data sharing. Furthermore, USATF could offer additional value by serving as a nongovernmental forum for investors to learn of new opportunities, voluntarily align around interesting projects, and provide a vehicle for the U.S. Government and investors to discuss their respective concerns and needs.

Operating alongside the TCC-OCA would mitigate USATF's limited *access to senior public leaders*. At the same time, this additional forum would expand the public-private model's *capacity to routinely engage private sector leaders*, some of whom may be more comfortable operating in this government-adjacent format. Furthermore, as with TCC-OCA, creating a new institution would facilitate adopting the necessary *competitive lens* and *broad technology scope*.

USATF's position outside of government would support its *independence in analysis* of technology trends. It could draw on a mixture of unclassified government assessments, industry data, private sector economic intelligence, and academic research.²¹² Governmental detailees and private sector and academic fellowships could supplement long-term staff to bring together a cross section of leading experts under one roof. And, given the presence of the TCC, USATF would need not function as an *accountable action arm* on its own.

Similar to the OCA, USATF's statutory basis would endow it with robust institutional *longevity* and support personnel *continuity*, enabling USATF to focus on long-term missions and providing

²¹⁰ See [Remarks by Erica Fuchs at Reimagining Industrial Policy for the Service and Tech Sectors](#), Brookings Institution at 1 hour, 9 (2022) (raising the data sharing concern).

²¹¹ See e.g., Pub. L. 98-525, [The United States Institute of Peace Act](#) (1984, amended 2008); Pub. L. 98-164, [A Bill to Authorize Appropriations for Fiscal Years 1984 and 1985 for the Department of State, the United States Information Agency, the Board for International Broadcasting, the Inter-American Foundation, and the Asia Foundation, to establish the National Endowment for Democracy, and for other purposes](#) (1983) (creating the National Endowment for Democracy as an independent, but federally funded, entity).

²¹² This collection of expertise and information would be particularly valuable as, often, much of the best technology knowledge exists in the private sector. See, e.g., Catherine McAnney, [The Need for Greater Technical Talent in the Government](#), Belfer Center on Science and International Affairs (2021).

institutional memory. Finally, as part of a package arrangement with the TCC and the OCA, USATF would *signal priority* as part of a significant overall action.

The challenge of the techno-economic competition is a complex and daunting one. A hybrid approach would combine the intellectual and operational firepower of multiple institutions to create a model where the sum provides greater power than any of its individual parts.

The Plans: Technology Action Plans to Move the Nation Towards Positional Advantages

The outcomes of a national technology strategy process are TAPs that move the entire U.S. innovation ecosystem towards a position of advantage. TAPs include both a technological, or micro, level of analysis as well as a macro analysis of the policy levers required to move the ecosystem in the right direction.

At the *micro level of analysis*, a TAP contains bold, even audacious, technology objectives to achieve national leadership in a specific technology or over a certain issue.²¹³ The technology objective must be informed but not be limited by a technology's TRL, a scale used by the U.S. Government and other actors to measure a technology's maturity.²¹⁴ Technology goals that seem impossible but are actually achievable – like landing a man on the moon and returning him safely to earth by the end of the decade – can push the ecosystem to achieve what it would not when left to itself. Informed by the TRL, selecting a technology objective requires developing a “theory of the case” for advantage. The resulting technology “minimum viable solution” maps a path for achieving a bold and crystal clear technology objective along a pressing, but realistic, timeline. It contains investable-level detail on the proposed technology pathway(s),²¹⁵ determines financial requirements and potential avenues of funding, identifies the best team (or teams) for the mission, and assigns a national mission manager responsible for its success.

At the *macro level of analysis*, advantage comes from an equation of relevant strategy and policy considerations. Thus, technology action plans must marry a technical pathway to a strategy for the ecosystem that nudges loose innovative potential from the status quo's constraints. This starts with mapping the factors that are exogenous to the core innovation, but necessary for its full realization. A diverse set of ecosystem stakeholders must inform and vet this mapping in order to chart a reasonable course among diverse government, commercial, civil liberties, and other

²¹³ Technology pathways can be charted from a future goal backwards – called back-casting – or from a technology's current state along a logical path from where it is today using methods such as tech trees or tech vectors. On back-casting, see John Holmberg & Karl-Henrik Robèrt, [Backcasting from Non-Overlapping Sustainability Principles – A Framework for Strategic Planning](#), The International Journal of Sustainable Development and World Ecology (2000). On tech trees, see [Foresight Institute's Tech Tree Project](#), Foresight Institute (last accessed 2022).

²¹⁴ See [Technology Readiness Assessment Guide](#), U.S. Department of Energy at 1-3 (2011).

²¹⁵ Technology pathways often take the form of a “platform.” While there are multiple definitions and a discourse surrounding the definition of a technology “platform,” in this context we define it to mean an endeavor that mobilizes resources in pursuit of a technology goal and moves the U.S. innovation ecosystem towards positional advantage in key sectors and technologies.

interests. The resulting TAP should at minimum cover the following elements associated with industrial strategy:²¹⁶

- **Infrastructure:** Can the technology integrate into existing relevant digital and/or physical infrastructure, or will new infrastructure be required to make the technology available to end users?
- **Supply Chain:** What critical inputs are needed to manufacture, scale, and deploy this technology and where do those inputs reside? How can cooperative public-private efforts help map essential inputs and devise a forward-leaning strategy that mitigates supply chain vulnerabilities?
- **Legal and Regulatory Regimes:** Do existing regimes fuel, rather than hinder, the domestic development and diffusion of technologies, and protect U.S. national security equities without undercutting commercial viability? Are new laws or regulations needed?
- **Industry Incentives:** Is the nation sufficiently enabling the private sector and smoothing the road for innovation through incentives such as information sharing mechanisms, tax credits, grants, or guaranteed purchases or reimbursement?
- **Talent:** Is the United States sufficiently cultivating, attracting, and retaining the commercial and academic talent driving technological progress in this area?²¹⁷

²¹⁶ Some macro elements of a TAP align with the key elements of a Techno-Industrial Strategy: Production (supply chain), Pipes (infrastructure), People (talent); Projection (incentives); and Pushback (legal & regulatory regimes). See [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project (2022); [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project (2022).

²¹⁷ See [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project at 40-44 (2022); [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 64-67 (2022).

Appendix A: Gaps - Methodology

Recognizing differences among the nature of these six technology sectors named in Mid-Decade Challenges to National Competitiveness and discussed in this report, we identified specific *metrics* that shed light on national opportunities or risks for each sector and tell the national competition story based on that sector's characteristics and maturity.

By reviewing available data against the selected sector-specific metrics, we then made our *assessments*. While grounded in data and our metric selection process, an assessment is ultimately a judgment based on the evidence available at a particular moment in time. For each technology, our assessments find either the United States or China is the technology leader at time of writing, or that leadership in the technology is contested.²¹⁸

- Technology leadership: We assess technology leadership to mean that today one country has a clear advantage over its rival for a specific technology, based on our selected metric(s).
- Contested technology: We assess leadership in a technology is contested when neither side possesses a clear advantage based on the metrics we have identified. This does not require that a technology hangs on a knife's edge as a 50-50 determination. Most basically, a contested technology indicates that either the United States or the PRC could be today's leader or both struggle to meet the metric.

As gaps change over time and sometimes rapidly, we assess the *direction* in which leadership over that technology appears to be trending. A directional judgment looks beyond established data to incorporate projections, plans, and early investment that have not yet taken effect. To do so, we take into account both the current criteria for advantage and emergent phenomena that may shape the contest over time. For this iteration, we limit our directional window to the period between today and 2025.²¹⁹

In some cases, data for the ideal metric was not available. In those instances, we turned to proxy indicator(s). The use of ideal or proxy indicators is a significant factor in the stated *confidence interval (low, moderate, high)* that accompanies each assessment and direction. An assessment of the current state of a technology based on ideal indicators yields a higher confidence level. Conversely, assessments that rely on proxy metrics can result in lower confidence levels. Likewise, for directions, actions underway (such as early-stage investment in physical plant or research and

²¹⁸ The United States does not compete alone. [Mid-Decade Challenges to National Competitiveness](#), Special Competitive Studies Project at 101-103 (2022). However, the gaps assessed in this document focus on whether the U.S. ecosystem is primed to compete in the unfolding techno-economic competition. Therefore, this gaps analysis primarily examines the U.S. and PRC innovation ecosystems, leaving for future analysis the collective strength of the United States plus its network of allies and partners.

²¹⁹ The contest over these technologies will almost certainly extend beyond this timeframe. However, we limit the period for our projections given the limits of the data available today and the still highly emergent and variable states of some technology sectors.

development) support a higher confidence level than mere statements of intent. Additional factors affecting confidence determinations include the source of the data used in the analysis, the timeliness of the data used, the maturity of the technology, and the extent to which a surprise or breakthrough could turn the tide on a particular technology.

China's Perceived "Gaps"

Rival perceptions of gaps are also critical to consider. Multiple analyses from Chinese outlets in recent years have offered insight into how PRC policymakers perceive relative U.S.-China technological positions. In 2018, a series of thirty-five S&T Daily articles identified the following "chokepoint" technologies where China was reliant on foreign sources or suppliers: **photolithography machines, aviation design software, high strength and aviation grade steels, and lithium battery separators.**²²⁰

More recently, a 2022 report from Peking University's Institute of International and Strategic Studies (IISS) assessed that the PRC was behind the United States along certain technology metrics, but ahead in others:²²¹

Areas China is Ahead:

- Commercial Drones
- Data-driven technologies (computer vision, image/facial recognition)
- 5G patents
- Closing the gap with global competition: Beidou global navigation satellite system (China's version of GPS)

Areas China is Behind:

- Volume of academic citations
- Investments in basic research
- Software (design tools; operating systems)
- High-end tech talent

²²⁰ Ben Murphy, [Chokepoints: China's Self-Identified Strategic Technology Import Dependencies](#), Center for Security and Emerging Technology (2022).

²²¹ This report was briefly published online but quickly removed.

Appendix B: Gaps - Analysis

Category: Software

Artificial Intelligence (AI)

Assessment:	Contested
Direction:	Contested

Confidence Interval:	Moderate
Confidence Interval:	Moderate

- Metrics:

National AI leadership should be judged across the “AI Stack” that considers computing power, algorithms, data, applications, integration, and talent. These elements in aggregate are necessary for a nation to both drive AI research frontiers and enable adoption. Concurrently, government attention on the technology through investments and action plans indicate national strategic direction.

- Analysis:

Based on current metrics and projected trend lines, we assess that AI is a **contested space** and is likely to **remain contested** as the United States and China compete across the AI stack.²²²

- Hardware:

The United States still leads in the design of cutting-edge chips, but this space is increasingly contested.²²³

- Data:

Performance of AI systems continues to correlate with access to significant amounts of training data. In aggregate, China leads in certain types of data due both to the sheer volume that its large population generates and its efforts to promote the accessibility of data. China has referred to data as an economic “factor of production”²²⁴ and has tried to break down stovepipes within the country to improve access to datasets. The International Data Corporation estimates that in 2018, China generated 7.6 zetabytes (ZB) of data (23 percent of total data generated globally), compared with 6.9ZB generated in the United States (20 percent of global data volume).²²⁵ By 2025, China is expected to generate 48.6ZB or 27.8 percent of the world’s data per year, while

²²² [Artificial Intelligence Index Report 2022](#), Stanford University Human-Centered Artificial Intelligence (2022); Graham Allison, et al., [The Great Tech Rivalry: China vs the U.S.](#), Belfer Center for Science and International Affairs (2021).

²²³ For more information, see the section on semiconductors of this appendix.

²²⁴ Lindsay Gorman, [China’s Data Ambitions: Strategy, Emerging Technologies, and Implications for Democracies](#), National Bureau of Asian Research (2021).

²²⁵ Saheli Roy Choudhury, [As information increasingly drives economies, China is set to overtake the US in race for data](#), CNBC (2019).

the United States is expected to generate 30.6ZB, or 17.4 percent.²²⁶ A major factor in the surge of data from China is from video surveillance.²²⁷ While this data has particular utility for computer vision-based applications, it may not be as useful for other applications of AI.

- Algorithms/Architectures:

The United States remains at the forefront of developing novel AI algorithms and architectures. For example, the release of OpenAI's GPT-3 in June 2020 catalyzed a rapidly growing ecosystem for the production and use of transformer-based large language models (LLMs) and, increasingly, image- and video-generating models.²²⁸ Nevertheless, while the utility of LLMs was first demonstrated by a U.S. research lab, and U.S. entities remain leaders in the field, at least eight PRC entities have released their own LLMs and image generation models and are beginning to demonstrate novel research.²²⁹ As the cost of training AI models decreases, new actors in both ecosystems will more easily have the tools to create customized algorithms for myriad purposes.²³⁰

²²⁶ Saheli Roy Choudhury, [As information increasingly drives economies, China is set to overtake the US in race for data](#), CNBC (2019) (citing David Reinsel, et al., [The Digitization of the World from Edge to Core](#), International Data Corporation (2018)).

²²⁷ David Reinsel, et al., [The Digitization of the World from Edge to Core](#), International Data Corporation (2018).

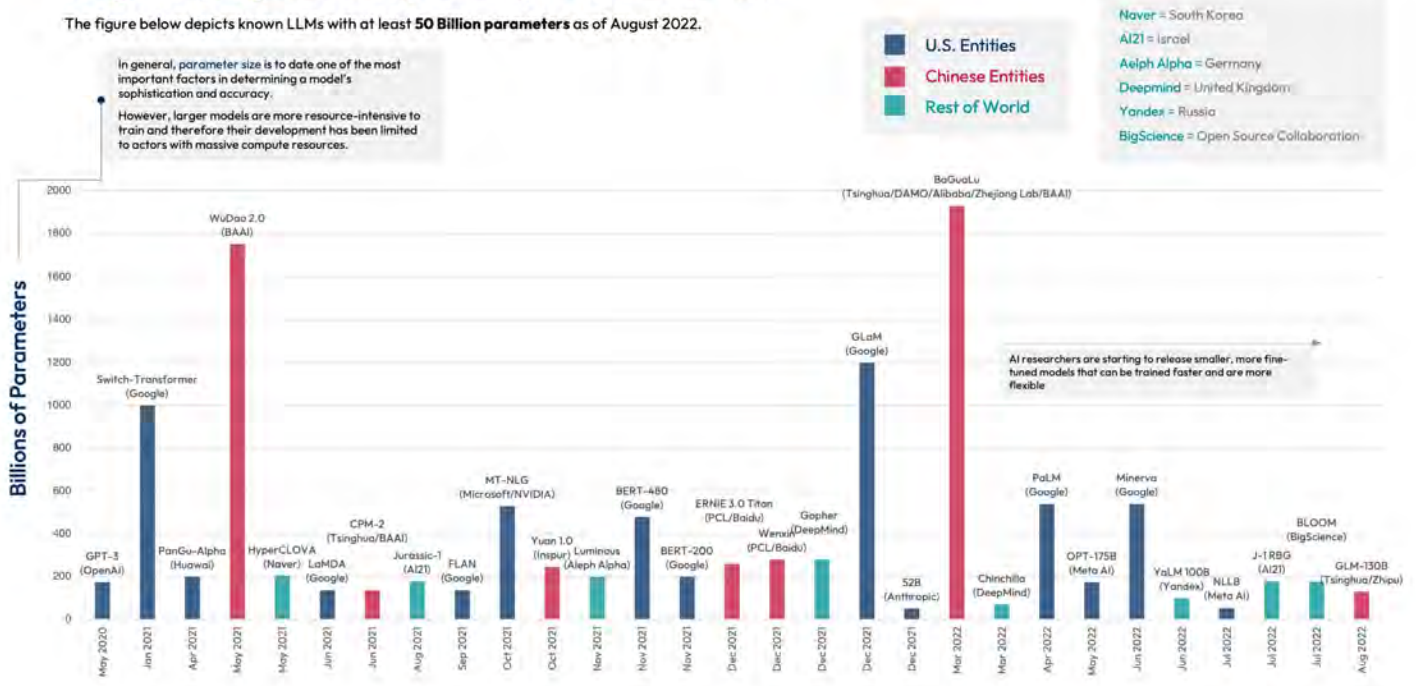
²²⁸ See Nathan Benaich & Ian Hogarth, [State of AI Report 2022](#), State of AI at slides 34-35 (2022).

²²⁹ One example of PRC-based novel research includes: Han Zhang, et al., [ERNIE-ViLG: Unified Generative Pre-training for Bidirectional Vision-Language Generation](#), arXiv (2021).

²³⁰ In October 2022 the startup Mosaic claimed to have trained a GPT3-equivalent model for a cost of \$450,000, compared to millions of dollars required to train GPT-3. See Jack Clark, [Import AI 304: Reality collapse thanks to Facebook; open source speech rec; AI culture wars](#), Import AI (2022). Additionally, Stable Diffusion, an open-source image model released in September 2022, reportedly cost some \$600,000 to train. See Matthias Bastian, [Training cost for Stable Diffusion was just \\$600,000 and that is a good sign for AI progress](#), The Decoder (2022).

Large Language Models by Country & Parameter Size²³¹

The figure below depicts known LLMs with at least 50 Billion parameters as of August 2022.



- Applications:

The race to deploy AI continues to unfold, and certain types of AI applications will matter more to the international competition than others. China’s AI ecosystem is increasingly competitive.²³² It has seen wide diffusion of computer vision-based applications – primarily for surveillance, which could afford Beijing an advantage via massive datasets and expertise that could be deployed for other strategic applications.²³³ Chinese researchers are also focusing their research in autonomous driving, and scene segmentation compared to their U.S. counterparts, based on review of publications.²³⁴

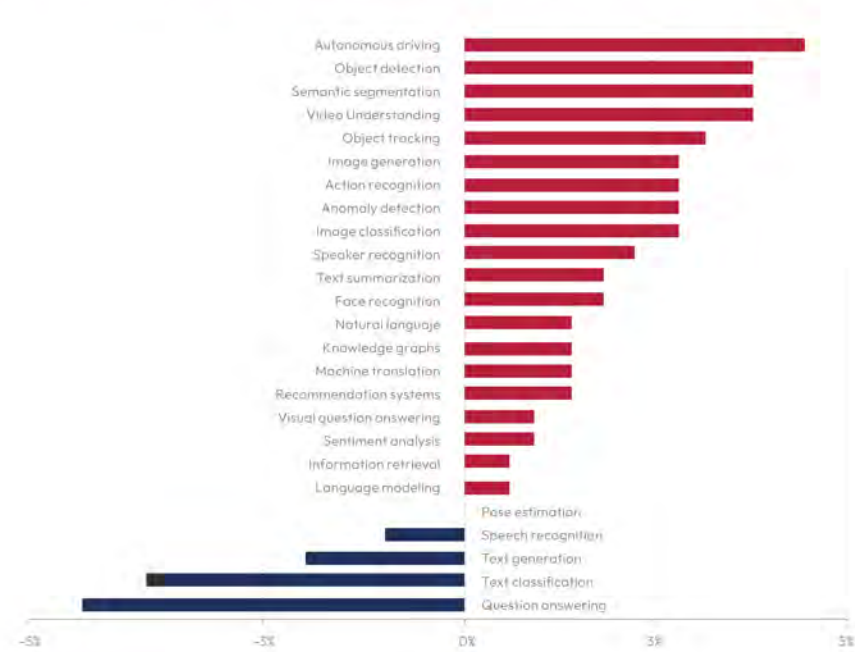
²³¹ SCSP Compilation of External Sources

²³² James Vincent, [China overtakes US in AI startup funding with a focus on facial recognition and chips](#), The Verge (2022).

²³³ SCSP Engagement with the founder of a natural language processing company (January 2022).

²³⁴ Nathan Benaich & Ian Hogarth, [State of AI Report 2022](#), State of AI (2022).

Prevalence of Machine Learning Research Areas in Chinese vs. U.S. Papers²³⁵



- Talent:

China leads the world in AI patent citations; however the U.S. likely still retains the world’s top AI talent.²³⁶ One common metric to measure the presence of AI talent is the country of origin (based on lead author) for papers presented at premier AI conferences. For example, in 2021 the United States led the way in the number of papers accepted at NeurIPS2021 with 1431 versus 411 for China.²³⁷ Similarly, the top four academic institutions by paper count were all U.S. universities (MIT, Stanford, CMU, UC Berkeley), with Tsinghua University coming in fifth and Peking University in eighth place. Together, these numbers show that while the United States still retains the lead, Chinese researchers are increasingly producing world class research.

- Policy/Governance:

While much has been made of China’s efforts to act on the National AI Development Plan that was published in 2017, the United States has also made strides in pursuing a more coordinated AI policy. The National Security Commission on AI completed its work in 2021 and Congress and the Executive Branch have enacted or implemented many of the Commission’s recommendations into law or practice.

²³⁵ Nathan Benaich & Ian Hogarth, [State of AI Report 2022](#), stateof.ai (2022).

²³⁶ See [The Global AI Talent Tracker](#), MacroPolo (2019).

²³⁷ [NeurIPS 2021 Announces Its 6 Outstanding Paper Awards, 2 Datasets and Benchmarks Track Best Paper Awards, and the Test of Time Award](#), SyncedReview (2021).

Internet Platforms/Social Media

Assessment:	U.S.-Lead
Direction:	Trend U.S.

Confidence Interval:	High
Confidence Interval:	Moderate

- Metric:

An ideal measure of global reach of popular internet platforms would be the percentage of users that are outside the largest internet platform companies’ countries of origin. Absent this data, monthly active users of social media platforms and global market share of search engines can serve as an imperfect proxy for global reach. The market capitalization of the leading Internet firms is another proxy measure for perceived global reach and influence.

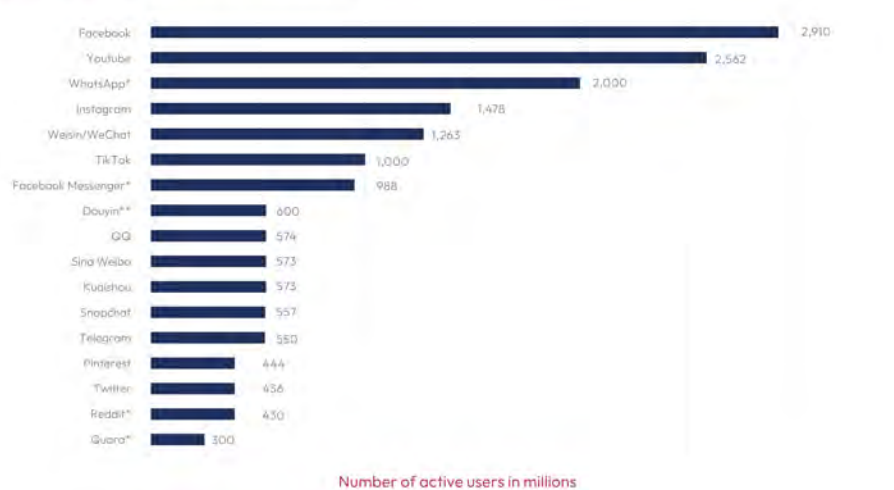
- Analysis:

Based on current metrics and projected trend lines, we assess **U.S. leadership** in internet platforms with a continued **direction toward U.S. advantage**.

The United States retains a durable lead in Internet Platforms/Social Media, yet should not lose sight of recent PRC success stories like TikTok. U.S. firms operate the leading Internet platforms which the majority of the world uses to connect, communicate,²³⁸ and find information.²³⁹ U.S.-based social media companies took the top four spots in monthly active users worldwide in October 2022, and Google had 92% of global search engine market share in October 2022.²⁴⁰

Most Popular Social Networks Worldwide as of January 2022²⁴¹

Ranked by number of monthly active users (in millions)

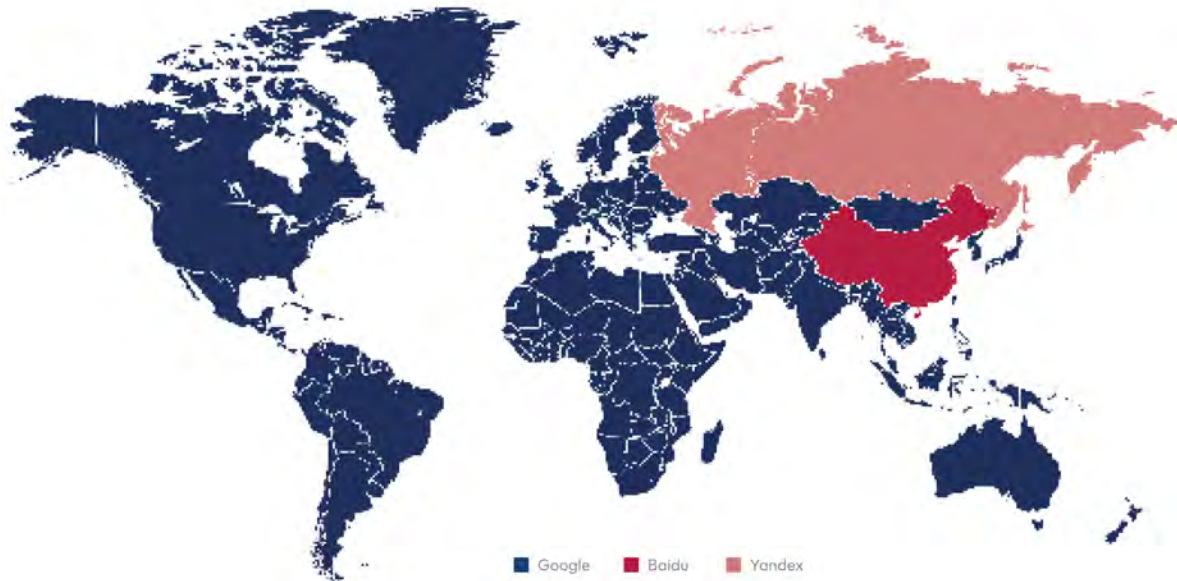


²³⁸ [Global Social Media Statistics](#), DataReportal (last accessed 2022).

²³⁹ [Search Engine Market Share Worldwide](#), Statcounter Global Stats (last accessed 2022).

²⁴⁰ [Global Social Media Statistics](#), DataReportal (last accessed 2022); [Search Engine Market Share Worldwide](#), Statcounter Global Stats (last accessed 2022).

²⁴¹ [Global Social Media Statistics](#), DataReportal (last accessed 2022).

Search Engine Market Share Worldwide from June - Aug 2022²⁴²

Yet the success of Bytedance's TikTok – fifth in global monthly active users without counting its domestic version's user base, the world's most downloaded mobile app in 2021,²⁴³ and the top social media app among North American teens in 2022²⁴⁴ – demonstrates that PRC companies are capable of rapidly gaining global reach. Future leadership could hinge on not only the power of the algorithms powering these platforms, but also in how well they adapt to the shifting global legal and regulatory environment for AI-applications and social media platforms.

²⁴² [Search Engine Market Share Worldwide](#), Statcounter Global Stats (last accessed 2022).

²⁴³ Simon Kemp, [Digital 2022: Global Overview Report](#), DataReportal (2022).

²⁴⁴ Emily A. Vogels, et al., [Teens, Social Media and Technology 2022](#), Pew Research Center (2022).

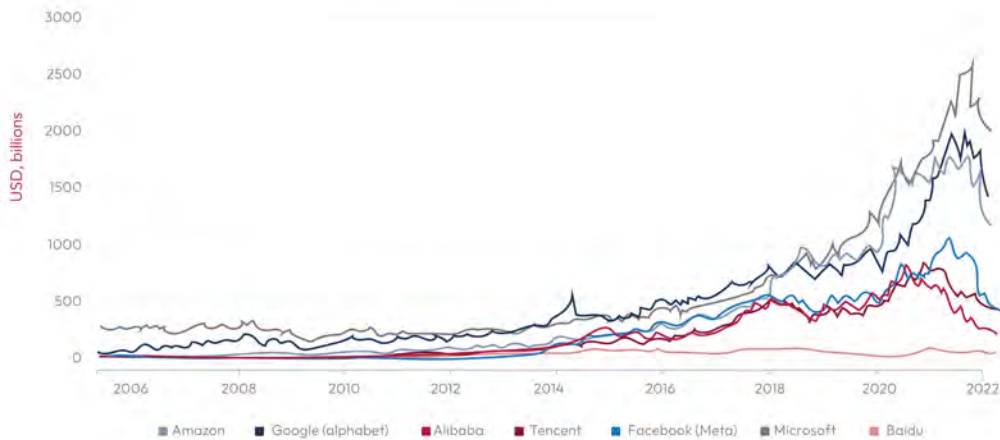
Mobile App Downloads²⁴⁵

Ranking by Total Number of Downloads Between January and December 2021



#	Mobile APP	Company
1	TIKTOK	BYTEDANCE
2	INSTAGRAM	META
3	FACEBOOK	META
4	WHATSAPP	META
5	TELEGRAM	TELEGRAM
6	SNAPCHAT	SNAP
7	FACEBOOK MESSENGER	META
8	ZOOM CLOUD MEETINGS	ZOOM
9	CAPCUT	BYTEDANCE
10	SPOTIFY	SPOTIFY

Seven Giants of the AI Age and Market Capitalization²⁴⁶



Lastly, market capitalization is an imperfect measure for global reach but reflects the perceived value of a firm’s reach and influence. By this measure, China’s big Internet technology companies still significantly lag behind their U.S. counterparts.

²⁴⁵ Simon Kemp, [Digital 2022: Global Overview Report](#), DataReportal (2022).

²⁴⁶ Fathom Financial Consulting Limited (2022) (SCSP-commissioned work product). Bytedance, owner of TikTok, is not publicly traded and is therefore not included in this chart. As of mid-2022 Bytedance had a valuation of approximately \$280 billion. [TikTok Owner ByteDance's Valuation Drops Below \\$300 Billion](#), Bloomberg (2022).

Category: Biotechnology²⁴⁷*Synthetic Biology*²⁴⁸

Assessment:	U.S.-Lead
Direction:	Trend U.S.

Confidence Interval:	Low
Confidence Interval:	Low

- Metric:

As synthetic biology is still an emerging sector, measuring patents and research article citations provides indications of innovative potential, while looking at the number of firms in this domain provides indications of an emerging commercial ecosystem. The lack of consistent global definitions for synthetic biology make it difficult to find metrics that can reliably capture the scope of entities engaged in this emerging sector, resulting in a low confidence score of the state and direction of this competition.

- Analysis:

We assess **U.S. leadership** in synthetic biology with a continued **direction toward U.S. advantage**, based on current metrics and projected trend lines. However, we have low confidence in these assessments based on the lack of data that reliably captures the current state of the synthetic biology sector.²⁴⁹

The United States is ahead in synthetic biology innovation and commercialization judging from the U.S. lead in publications and patents, as well as the number of synthetic biology firms when compared to China.²⁵⁰ According to a U.S.-based synthetic biology industry association, the United States in 2019 had 354 synthetic biology firms versus four in China.²⁵¹

Yet since 2019, China has seen a significant increase in venture capital investment in biotechnology²⁵² (which includes firms beyond just synthetic biology), and the release of a new

²⁴⁷ There is no consensus definition for biotechnology. The [NSF](#) and [OECD](#) use the definition of “the broad application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.” As such, this definition encompasses sectors including biopharmaceuticals and synthetic biology.

²⁴⁸ The National Academies of Science Engineering and Medicine defines synthetic biology as follows: “collectively refers to concepts, approaches, and tools that enable the modification or creation of biological organisms.”

²⁴⁹ One indicator that would be a stronger measure of synthetic biology competitiveness would be a measure of bioproduction capacity. [Biodefense in the Age of Synthetic Biology](#), National Academies of Sciences, Engineering, and Medicine (2018).

²⁵⁰ [Safeguarding the Bioeconomy](#), National Academies of Sciences, Engineering, and Medicine (2020).

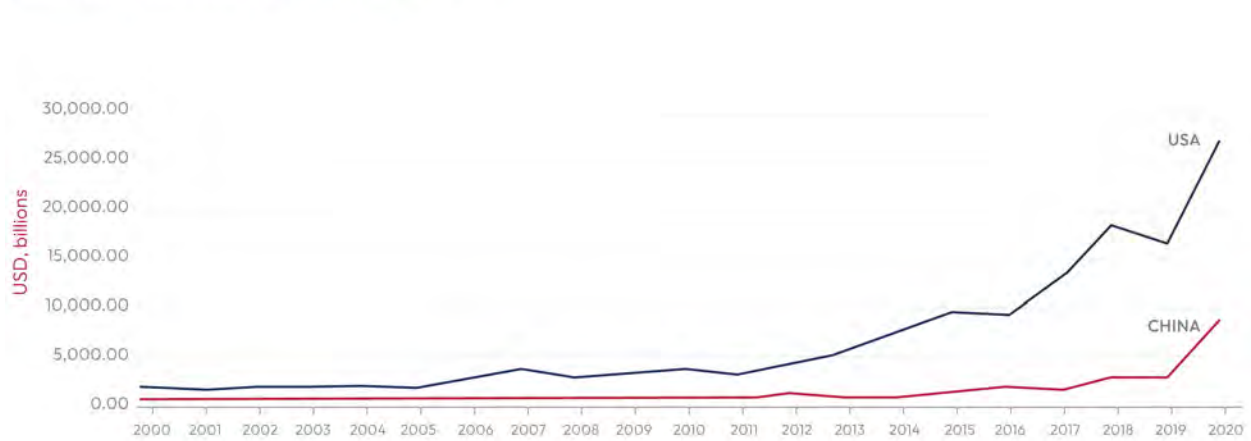
²⁵¹ [Defining the Bioeconomy](#), SynBioBeta at 14 (2019).

²⁵² [Production and Trade of Knowledge- and Trade-Intensive Industries](#), National Science Foundation (2022) (NSF science and engineering indicators using data from Pitchbook).

five-year plan by Beijing that calls for development of China’s synthetic biology sector.²⁵³ This suggests that the number of synthetic biology firms is likely higher today amidst the emergence of giants such as BGI and Wuxi Biologics.

Total Biotechnology Venture Capital Raised²⁵⁴

2000-2020 (in millions of USD) - US vs China

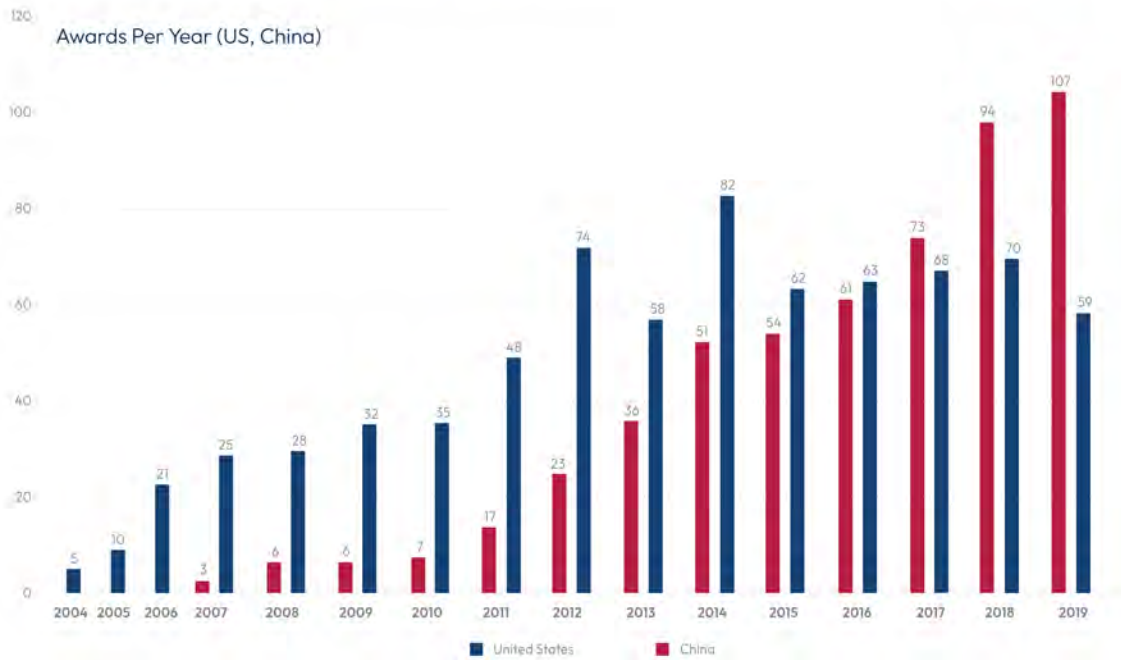
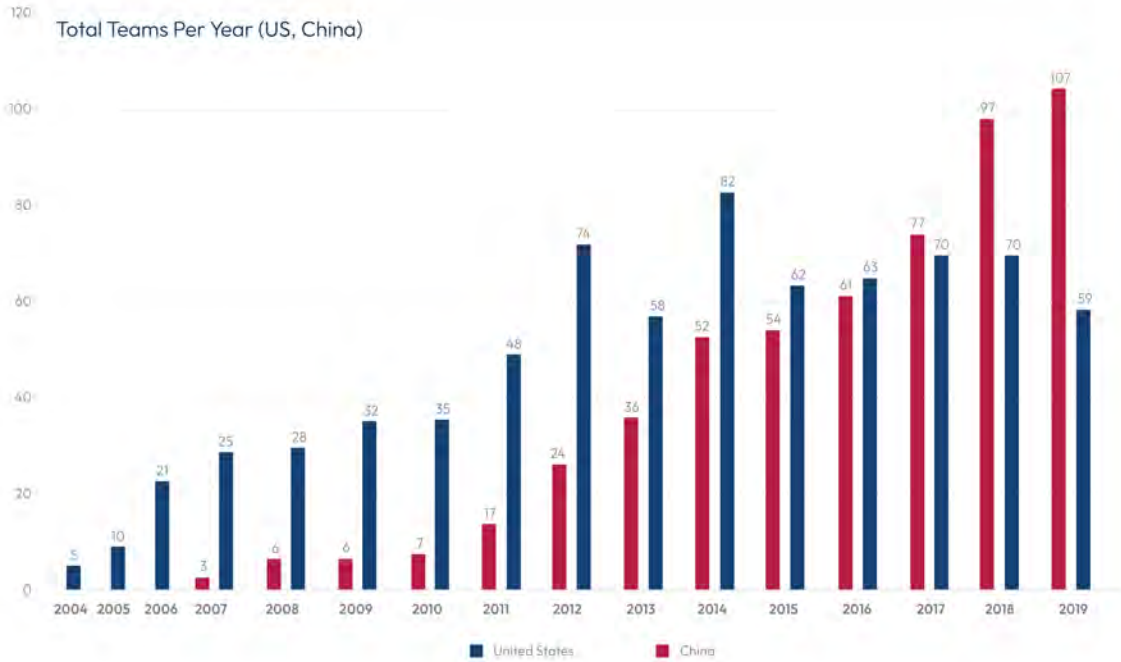


Chinese students are also showing a growing interest in synthetic biology through their participation in the International Genetically Engineered Machine (iGEM) competition, the premier synthetic biology competition in the world. The number of PRC teams participating each year has increased substantially over the past decade. These teams are also performing well at the competition, with PRC teams surpassing the U.S. teams in total award count at the competition each year since 2017. These trends suggest that the talent pipeline in China may be strengthening and capabilities in this field will continue to improve.

²⁵³ [CSET Original Translation: China's 14th Five-Year Plan](#), Center for Security and Emerging Technology at 14 (2021).

²⁵⁴ Ledia Guci & Abigail Okrent, [Enabling Technologies](#), U.S. National Science Foundation Science & Engineering Indicators (2022).

iGEM Competition²⁵⁵



²⁵⁵ [The Database](#), iGEM (last accessed 2022).

Biopharmaceuticals

Assessment:	U.S.-Lead
Direction:	Trend Contested

Confidence Interval:	Moderate
Confidence Interval:	Moderate

- Metric:

Biopharmaceuticals – medicines that are produced using biological processes – are emerging as the key technology driving innovation of novel drugs.²⁵⁶ As novel drugs usually spend seven-to-ten years in the research and development pipeline before being approved, one measure of national competitiveness in this emerging sector is to examine the number of drugs from biopharmaceutical firms by country.

- Analysis:

Based on current metrics and projected trend lines, we assess **U.S. leadership** in biopharmaceuticals with a **direction toward becoming a contested space**.

U.S. companies still account for the largest share (46 percent) of biopharmaceutical-based drugs in the research and development pipeline. However, PRC companies' share has increased rapidly, from six percent in 2016 to 17 percent in 2021.²⁵⁷ As new drug innovation continues to shift towards biopharmaceuticals, PRC firms could emerge as an increasingly competitive player in the pharmaceutical industry since 83 percent of new drug research and development in China is conducted by emerging biopharmaceutical companies.²⁵⁸ This demonstrates the growing prowess of PRC pharmaceutical firms to capitalize on a paradigm shift, taking the nation's industry beyond its traditional focus on manufacturing generics.²⁵⁹ China is already the world's leading producer of active pharmaceutical ingredients, providing China a strong springboard upon which to build.²⁶⁰

²⁵⁶ [Global Trends in R&D](#), IQVIA (2022).

²⁵⁷ [Global Trends in R&D](#), IQVIA at 3 (2022).

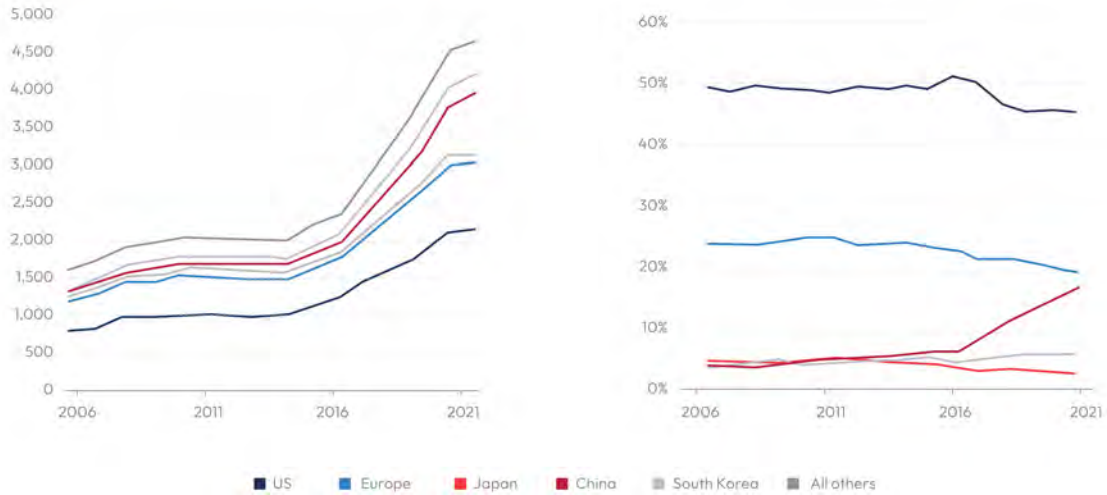
²⁵⁸ [Global Trends in R&D](#), IQVIA at 50 (2022).

²⁵⁹ Kiki Han, et al., [The Dawn of China's Biopharma Innovation](#), McKinsey (2022).

²⁶⁰ [Global Active Pharmaceutical Ingredients \(API\) Market Report 2021](#), Research and Markets (2021).

Emerging biopharma drug development is rising rapidly, particularly in China, whose share has added 11% in 5 years²⁶¹

Exhibit 42: Number of drugs and country share of emerging biopharma pipeline Phase I to regulatory submission based on company headquarter location, 2006-2021



PRC firms’ growing share of biopharmaceutical R&D is also reflected in its efforts to deliver pioneering novel treatments for cancer such as chimeric antigen receptor (CAR) T-cell therapy,²⁶² in which PRC firms’ capabilities are regarded as being at par with U.S.-based companies.²⁶³ Additionally, as AI-driven drug discovery continues to gain traction,²⁶⁴ PRC biopharmaceutical firms may increasingly be able to capitalize on the robust AI talent and resources available in China.²⁶⁵

Category: Networks

5G

Assessment:	PRC-Lead
Direction:	Trend Contested

Confidence Interval:	Moderate
Confidence Interval:	Low

- Metric:

The 5G competition continues to unfold along two key fronts – the race to supply the equipment to build 5G networks around the world, and the race between China and the United States to

²⁶¹ [Global Trends in R&D 2022](#), IQVIA Institute (2022).

²⁶² David Crow, et al., [Healthcare: Cancer breakthrough leads China’s biotech boom](#), Financial Times (2018).

²⁶³ Mark Kazmierczak, et al., [China’s Biotechnology Development: The Role of US and Other Foreign Engagement](#), U.S.-China Economic and Security Review Commission at 43 (2019).

²⁶⁴ Neil Savage, [Tapping into the drug discovery potential of AI](#), Nature (2021).

²⁶⁵ For more information, see the artificial intelligence section of this appendix.

deploy 5G networks within their borders as the enabling infrastructure to drive new innovations. Measuring the 5G competition requires looking both at the market share of firms supplying 5G equipment around the world, and also how successfully each country is deploying 5G to their populations.

- Analysis:

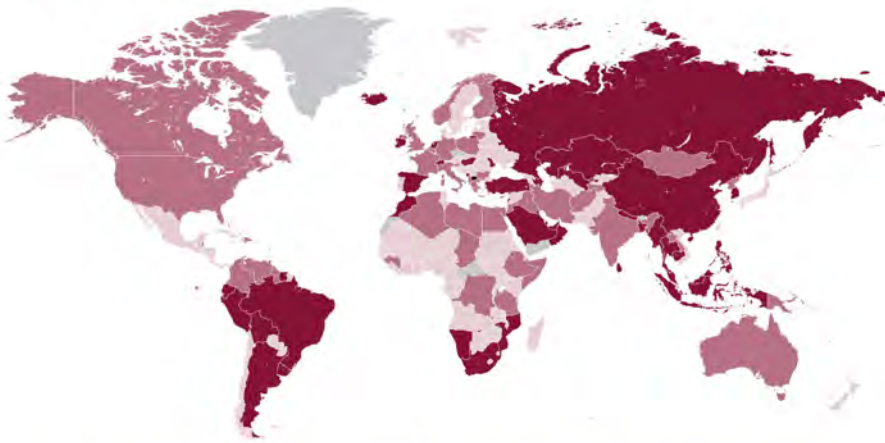
Based on current metrics and projected trend lines, we assess **PRC leadership** in 5G with a **direction toward becoming a contested space**.

While Huawei and ZTE still hold a commanding share of the global telecommunications equipment manufacturing market, U.S. policy actions have started to bite.²⁶⁶

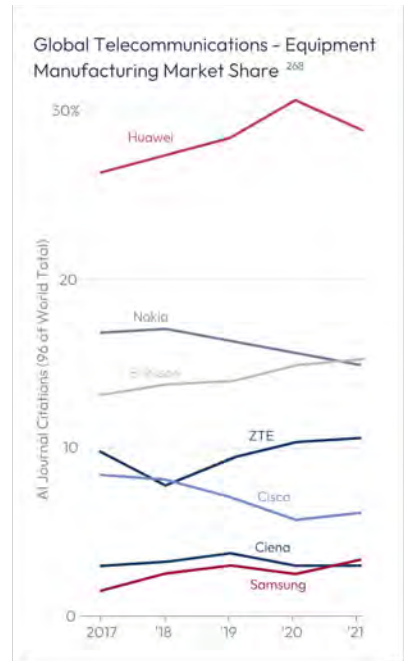
Huawei & ZTE Telecom Presence²⁶⁷

PRC telecommunications companies Huawei and ZTE have expanded their reach across the globe.

● 5G ● 4G/3G ● Other ● Insufficient data



Note: "5G" indicates Huawei or ZTE 5G networks or technology is either already in use or planning to be used. "4G/3G" indicates Huawei or ZTE has built either 4G or 3G networks. "Other" includes other relationships with Huawei or ZTE, including telecom equipment sales, data centers, smart cities, investments, overseas offices, research partnerships, R&D labs, talent exchanges, fiber-optic cables, subsidiaries, surveillance equipment sales, and training.

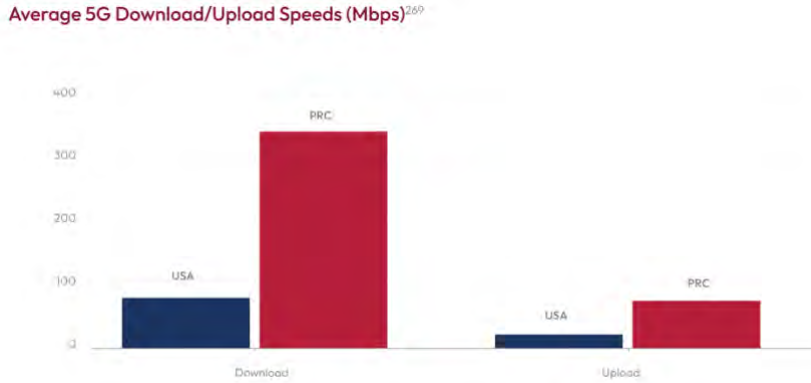


China's average national 5G download and upload speeds are faster than those in the United States. New sources of federal funding will accelerate America's digital infrastructure buildout, but precise and rigorous implementation will be key.

²⁶⁶ John McCormick, [Huawei, Ericsson or Nokia? Apple or Samsung? U.S. or China? Who's Winning the 5G Races](#), Wall Street Journal (2022).

²⁶⁷ SCSP analysis of publicly available information and databases.

²⁶⁸ John McCormick, et al., [Huawei, Ericsson, or Nokia? Apple or Samsung? U.S. or China? Who's Winning the 5G Race?](#), Wall Street Journal (2021).



The battle over 5G will next shift to be a contest between who is best positioned to take advantage of the networks and develop novel applications,²⁷⁰ an area where America has traditionally excelled. Despite China’s initial success in deploying faster 5G networks, it has not yet made significant headway in building new applications that drive widespread consumer adoption and additional investment.²⁷¹

While much attention has been paid to the deployment of 5G base stations, another key element of wireless networks is their ability to connect to a wired (primarily fiber optic) network for backhaul of the network traffic. In this measure too, China is leading. In China, fixed broadband subscribers are overwhelmingly connected over fiber, while U.S. users access broadband through a diverse mixture of DSL, cable, fiber, and satellite, with cable dominating the market.²⁷² The wider availability of fiber to the home in China suggests a greater availability of deep fiber which is important to allow for the connection of wireless base stations.

²⁶⁹ SCSP-commissioned work product (2022).

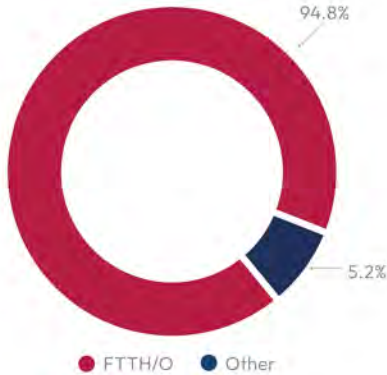
²⁷⁰ Mark Cameron, [Telcos Aren’t Ready To Capitalize On The Value Of 5G–Yet](#), Forbes (2022).

²⁷¹ For a fuller analysis of digital infrastructure and recommendations for U.S. action, see [Restoring the Sources of Techno-Economic Advantage, Special Competitive Studies Project](#), at 30-39 (2022).

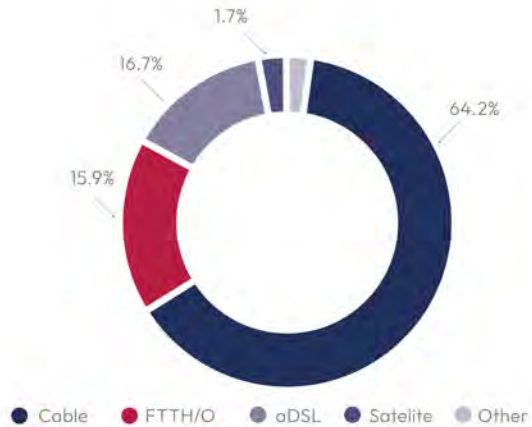
²⁷² Completion of Major Indicators of the Communications Industry in the First Half of 2022 (2), China’s Ministry of Industry and Information Technology (2022); [‘Fixed Broadband Deployment Data: December 2019’](#), Federal Communications Commission (2020).

SPECIAL COMPETITIVE STUDIES PROJECT

China Broadband Subscriptions by Access Medium - Jul 2022²⁷³



US Residential Connections by Access Medium - Dec 2019²⁷⁴



Next Generation Wireless Networks (6G, LEO, etc.)

Assessment:	Contested
Direction:	Trend Contested

Confidence Interval:	Moderate
Confidence Interval:	Low

- Metric:

Next generation wireless network technologies such as 6G are starting to be researched, including technical discussions.²⁷⁵ Additionally, low earth orbit (LEO) satellites and other non-terrestrial networks are emerging as alternative paradigms to how network access is delivered. As the contours of these are still being determined, early metrics for national leadership – patents and key players in these spaces – can only be applied with low confidence.

- Analysis:

Using the above metrics, we assess next generation wireless networks to be a **contested space** that will likely **remain contested**.

The United States’ lack of major network equipment manufacturers could hamper its competitiveness in developing and producing future 6G equipment.²⁷⁶ An analysis from a Japan-

²⁷³ Completion of major indicators of the communications industry in the first half of 2022 (2), China’s Ministry of Industry and Information Technology (2022).

²⁷⁴ [Fixed Broadband Deployment Data: December 2019](#), U.S. Federal Communications Commission (2020).

²⁷⁵ Shirley Zhao, et al., [Forget 5G, the U.S. and China Are Already Fighting for 6G Dominance](#), Bloomberg (2021).

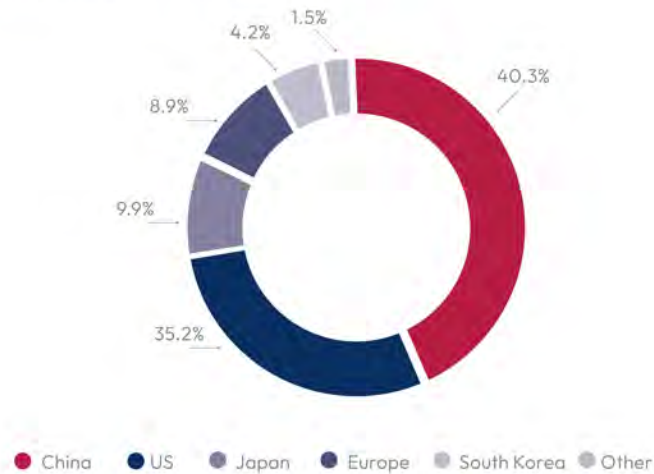
²⁷⁶ Michael Koziol, [6G Is Years Away, but the Power Struggles Have Already Begun](#), IEEE Spectrum (2021).

based research company of 20,000 patents in 2021 found that PRC firms – led by Huawei – currently control 40 percent of patents around the core technologies that could define 6G.²⁷⁷

6G patent applications by country/region²⁷⁸

(As of August 2021, in percent)

Applications for nine areas related to core 6G technology



Since standards and technologies are being defined, this distribution could shift significantly. The United States’ position remains strong when considered in aggregate with those of South Korea, Europe, and Japan. Perhaps recognizing this potential, an industry alliance of U.S., European, Korean and Japanese firms has emerged to coordinate respective efforts in this space.²⁷⁹

Additionally, space-based delivery of wireless network access is an emerging paradigm which could change the composition of future wireless networks.²⁸⁰ The number of U.S. firms already operating or planning to deploy space-based network access suggests that the United States has an early lead in this emerging field, however Beijing has initiated an effort to build a 13,000 satellite constellation,²⁸¹ and a PRC startup recently launched its first test satellites.²⁸²

²⁷⁷ Naoki Watanabe, [China Accounts for 40% of 6G Patent Applications: Survey](#), Nikkei Asia (2022).

²⁷⁸ Naoki Watanabe, [China Accounts for 40% of 6G Patent Applications: Survey](#), Nikkei Asia (2022).

²⁷⁹ [NextG Alliance](#), NextG Alliance (last accessed 2022).

²⁸⁰ Claudia Marquina, [How Low-Earth Orbit Satellite Technology Can Connect the Unconnected](#), World Economic Forum (2022); Hope King, et al., [The Space Race for Our Cellphones](#), Axios (2022).

²⁸¹ Andrew Jones, [Shanghai Signs Agreement with China’s Megaconstellation Group, Aims to Foster Commercial Space Hub](#), SpaceNews (2022).

²⁸² Andrew Jones, [China Launches Test Satellites for Broadband Constellation](#), SpaceNews (2022).

Category: Energy

Fusion Energy

Assessment:	U.S.-Lead
Direction:	Trend U.S.

Confidence Interval:	High
Confidence Interval:	Low

- Metric:

While fusion energy has long been a line item on government R&D budgets, private startups are driving the field forward and shrinking the projected timelines for commercialized fusion. Since commercially-practical fusion has yet to be demonstrated, we compare the United States and China’s relative investments in achieving a fusion breakthrough.

- Analysis:

Based on current metrics and projected trend lines, we assess **U.S. leadership** in nuclear fusion with a continued **direction toward U.S. advantage**.

Commercial activity points to a **U.S. lead** in achieving the first demonstration reactor. The United States is home to at least 21 fusion companies – more than half of the known fusion companies in the world – which as of 2022 have attracted over \$3.9 billion in investment.²⁸³ China’s one known commercial (but state-backed) fusion company, ENN Energy Holdings, has raised \$200 million.²⁸⁴ Other PRC fusion efforts include a startup, Energy Singularity, that has raised an estimated \$59 million,²⁸⁵ and a government backed research effort called the Experimental Advanced Superconducting Tokamak which in 2021 set a world record for keeping a plasma stable at high temperature.²⁸⁶ More recently, Beijing approved construction of a Z-pinch machine based “Z Fusion Fission Reactor” for completion by 2025 with ambitious plans to have the machine producing power by 2028.²⁸⁷ This approach varies significantly from the common approaches taken by U.S.-based startups and research teams.

Yet once commercially-relevant performance is achieved, possibly as soon as 2024, fusion will ultimately be a competition over whose ecosystem can scale and commercially deploy the

²⁸³ SCSP analysis of company-reported funding data compiled in Fusion Industry Association’s 2022 report: [The Global Fusion Industry in 2022](#).

²⁸⁴ SCSP analysis of company-reported funding data compiled in Fusion Industry Association’s 2022 report: [The Global Fusion Industry in 2022](#).

²⁸⁵ See [Energy Singularity - Funding, Financials, Valuation & Investors](#), Crunchbase (last accessed 2022).

²⁸⁶ Ben Turner, [China's \\$1 Trillion 'Artificial Sun' Fusion Reactor Just Got Five Times Hotter Than the Sun](#), Live Science (2022).

²⁸⁷ Stephen Chen, [China's Top Weapons Scientist Says Nuclear Fusion Power is 6 years Away](#), South China Morning Post (2022).

technology.²⁸⁸ The U.S. Government is paying attention, and recently launched a decadal vision for commercial fusion energy.²⁸⁹

The PRC also has several government fusion initiatives and has called for “comprehensive research facilities for critical systems of fusion reactors” in its 14th Five Year Plan.²⁹⁰ Once the science has been proven, the PRC’s ecosystem would likely be ready to act quickly to rapidly catch up and scale the technology – potentially as it did with solar photovoltaics a decade ago.²⁹¹ U.S. allies including the UK,²⁹² Japan,²⁹³ and Canada²⁹⁴ also have national fusion plans, and the UK has announced the location of a national pilot plant.²⁹⁵ Looking beyond 2025, we can expect the fusion competition to become more contested. The United States may have an edge in fusion today, but sustained public-private efforts will be required to make that lead enduring.

Advanced High-Capacity Batteries

Assessment:	PRC-Lead
Direction:	Trend PRC

Confidence Interval:	High
Confidence Interval:	High

- Metric:

Batteries are an essential component to the transportation and renewable energy-based power grids of the future. National competitiveness in batteries requires not only the capacity to produce the batteries but a reliable supply chain that ensures access to the necessary raw materials.

- Analysis:

Based on current metrics and projected trend lines, we assess **PRC leadership** in advanced high-capacity batteries with a continued **direction toward PRC advantage**.

²⁸⁸ Energy Report Part 2: Energy Generation, TechNext (2022) (*SCSP commissioned work product*).

²⁸⁹ [Readout of the White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy](#), The White House (2022).

²⁹⁰ [CSET Original Translation: China's 14th Five-Year Plan](#), Center for Security and Emerging Technology at 14 (2021).

²⁹¹ [The Impact of China’s Production Surge on Innovation in the Global Solar Photovoltaics Industry](#), Information Technology & Innovation Foundation (2020).

²⁹² A £222 million public-private partnership will build a pilot plant by 2040 and another £184 million public-private partnership will lay the foundations for commercial fusion innovation. See [Ten Point Plan for a Green Industrial Revolution](#), UK Government at 26 (2020).

²⁹³ Yuichi Ogawa, [Research and Development Policy on Fusion Energy in Japan](#), National Academies of Science (2018).

²⁹⁴ [Fusion 2030 – A Roadmap for Canada](#), Canadian Nuclear Society (last accessed 2022).

²⁹⁵ The UK announced in October a power station in Nottinghamshire as the site for a prototype fusion plant it plans to build by 2040. A concept design for the plant is expected to be completed by 2024. See [Site of UK’s First Fusion Energy Plant Selected](#), UK Government (2022).

China is currently leading in advanced high-capacity batteries based on the dominance of PRC firms in both mining and processing the essential critical minerals, and their significant share of global lithium-ion battery production.²⁹⁶ Lithium-ion batteries were developed between the 1970s and 1990s in Japan, France, and the United States. Yet, battery experts estimate that the United States has fallen about 10 years behind the PRC.²⁹⁷ The PRC achieved global battery supply chain dominance through massive subsidies, a global strategy for raw materials, and forced technology transfers. PRC firms have acquired “ownership interests in mines and processing facilities in Africa, Australia, Europe, North America, and South America.”²⁹⁸

The advanced high-capacity batteries of today are primarily lithium-ion based and rely on metals such as nickel, cobalt, graphite, and lithium. China currently dominates all four, refining: 68 percent of the world’s nickel,²⁹⁹ 72 percent of cobalt, 100 percent of graphite,³⁰⁰ and 61 percent of lithium.³⁰¹ China dominates production of battery cell components with 91 percent of global anode production capacity and 81 percent of global cathode production capacity.³⁰² On manufacturing, China in 2020 accounted for the majority of global lithium-ion battery production capacity at 77 percent, or 250 giga-watt hours (GWh), with the U.S. at only 9 percent (42 GWh), Asia 8 percent (36 GWh) and the EU 6 percent (28 GWh).³⁰³ Even as the United States continues to invest in domestic battery production, China is still projected by industry analysts to have 226 large scale battery factories (70 percent of global capacity) versus 23 in the United States by 2031.³⁰⁴

²⁹⁶ Martin Placek, [Share of the Global Lithium-Ion Battery Manufacturing Capacity in 2021 with a Forecast for 2025, by Country](#), Statista (2022); Govind Bhutada, [Mapped: EV Battery Manufacturing Capacity, by Region](#), Visual Capitalist (2022); [Global Gigafactory Pipeline Hits 300; the PRC Dominates but the West Gathers Pace](#), Benchmark Mineral Intelligence (2022).

²⁹⁷ Jim Greenberger, [The Challenge of Building a Lithium Battery Supply Chain in North America](#), NAATBatt International (2021).

²⁹⁸ John D. Graham, et al., [How the PRC Beat the US in Electric Vehicle Manufacturing](#), Issues in Science and Technology (2021); Agatha Kratz, et al., [Circuit Breakers: Securing Europe’s Green Energy Supply Chains](#), European Council on Foreign Relations (2022).

²⁹⁹ Rodrigo Castillo, [China’s Role in Supplying Critical Minerals for the Global Energy Transition](#), Brookings Institution (2022).

³⁰⁰ [America’s Strategy to Secure the Supply Chain for a Robust Clean Energy Transition](#), U.S. Department of Energy at 13 (2022).

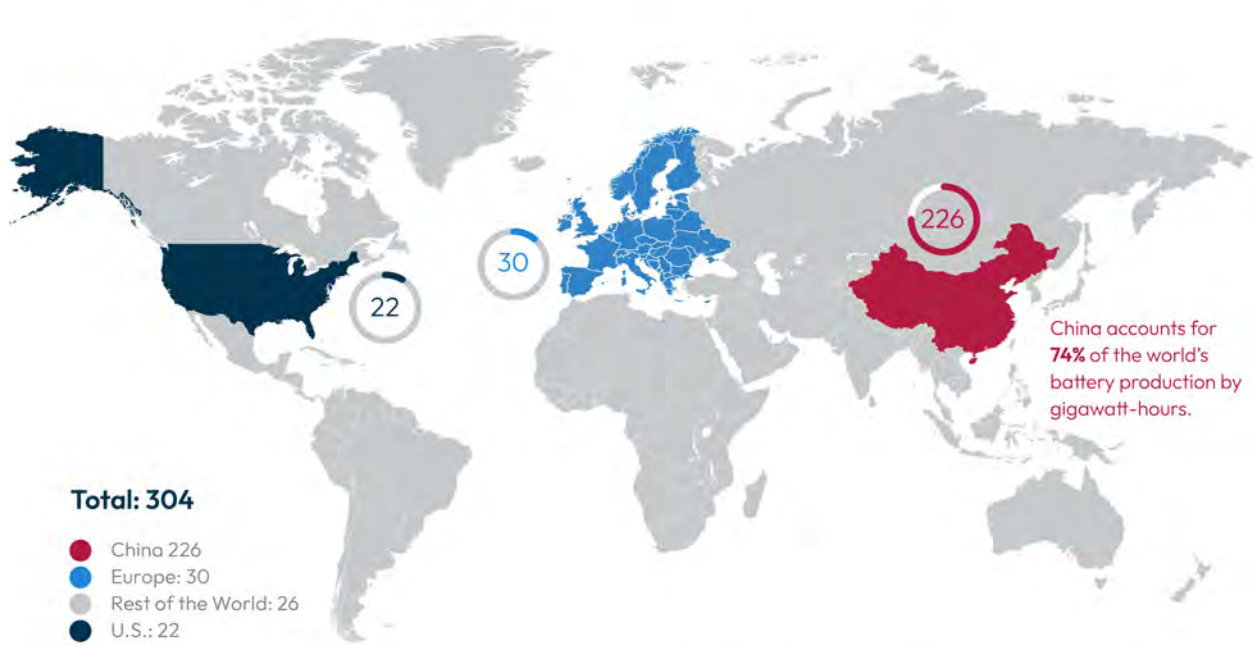
³⁰¹ [America’s Strategy to Secure the Supply Chain for a Robust Clean Energy Transition](#), U.S. Department of Energy (2022).

³⁰² [What Does the U.S. Inflation Reduction Act Mean for the EV Battery Supply Chain?](#), Benchmark Minerals (2022).

³⁰³ [Top Electric Vehicle Markets Dominate Lithium-Ion Battery Capacity Growth](#), S&P Global Market Intelligence (2022).

³⁰⁴ [Global Gigafactory Pipeline Hits 300; China Dominates But the West Gathers Pace](#), Benchmark Mineral Intelligence (2022).

Battery Megafactories Planned or Built³⁰⁵



Battery Megafactory: A battery production factory that produces at least 1 gigawatt-hour (GWh) of capacity per year.

Despite China’s supply chain and production dominance today, the United States could leapfrog the PRC’s bet on aging lithium-ion technology. New forms of non-lithium-based batteries, such as molten-salt batteries, are maturing rapidly and offer the potential for similar energy densities and costs.³⁰⁶ Further development and adoption of battery recycling technology could also reduce dependence on critical minerals produced and processed in China.³⁰⁷

Category: Computing

Quantum Computing

Assessment:	U.S.-Lead
Direction:	Trend Contested

Confidence Interval:	Moderate
Confidence Interval:	Low

³⁰⁵ [Global Gigafactory Pipeline Hits 300; China Dominates But the West Gathers Pace](#), Benchmark Mineral Intelligence (2022).

³⁰⁶ Energy Report Part 1: Energy Storage, TechNext (2022) (*SCSP commissioned work product*). For policy recommendations on strengthening the U.S. battery supply chain, including by investing in alternative battery chemistries, see [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project at 26-27 (2022).

³⁰⁷ [Lithium-Ion Battery Recycling—Overview of Techniques and Trends](#), ACS Energy Letters at 712-719 (2022).

- Metrics:

Demonstrated technical progress is the primary indicator of quantum computing capability alongside innovation metrics such as research papers and patents. However, due to the national security applications of quantum computing and the role of governments in advancing the field it is likely that detailed information on technical advances, funding, and personnel are limited in the open source.

- Analysis:

Based on current metrics and projected trend lines, we assess **U.S. leadership** in quantum computing with a **direction toward a contested space**.

The United States is the current leader in quantum computing when considering demonstrated technical progress as measured by teams who have built machines demonstrating quantum advantage.³⁰⁸ The United States also has a larger number of public and private actors engaged in the U.S. quantum computing ecosystem, primarily focused on developing quantum computing for a broader range of applications such as scientific discovery and materials research. However, PRC researchers continue to demonstrate significant achievements, receive significant government funding,³⁰⁹ and innovative potential – second only to the United States³¹⁰ – when judging from patent assignees.

Chinese researchers are likely at technical parity with the United States in one approach to quantum computing: superconducting qubits.³¹¹ Beijing is continuing to invest heavily to ensure continued progress in what Beijing deems to be a strategically important sector, with a particular focus on code-breaking applications.³¹²

The United States also continues to drive the frontiers of quantum research, ranking first in the world for quantum computing publications with high scientific impact (as quantified by academic citations).³¹³ Yet similar to AI, China has proven nimble at replicating U.S. breakthroughs and increasingly achieving their own. PRC researchers announced two quantum computers in 2021 –

³⁰⁸ Lars Madsen, et al., [Quantum computational advantage with a programmable photonic processor](#), Nature (2022); Frank Arute, et al., [Quantum supremacy using a programmable superconducting processor](#), Nature (2019).

³⁰⁹ Qiang Zhang, [Quantum Information Science in China](#), Quantum Science (2019).

³¹⁰ Edward Parker, et al., [An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology](#), RAND Corporation (2022); Computing Report, TechNext (2022) (*SCSP commissioned work product*).

³¹¹ Edward Parker, et al., [An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology](#), RAND Corporation (2022).

³¹² [CSET Original Translation: China's 14th Five-Year Plan](#), Center for Security and Emerging Technology (2021).; Stephen Chen, [Chinese Scientists Say They May Be a Step Closer to a Quantum Code-Breaking Machine](#), South China Morning Post (2022)

³¹³ Edward Parker, et al., [An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology](#), RAND Corporation (2022).

Zuchongzhi 2.1³¹⁴ (66 qubit superconducting) and Jiuzhang 2.0³¹⁵ (a photonic quantum computer) – which the researchers claim demonstrate quantum advantage to take on more challenging tasks and operate faster than Google's Sycamore machine.³¹⁶

Semiconductors

Assessment:	Contested
Direction:	Trend U.S.

Confidence Interval:	Moderate
Confidence Interval:	Low

- Metric:

A range of microelectronics enable our modern world from consumer electronics to defense systems. A nation should possess consistent and resilient access to semiconductors across all nodes.³¹⁷ Consequently, we assess semiconductor leadership as a composite of a country's: **(1)** access or control over the technological inputs into the semiconductor production process, including core IP for chips, electronic design automation (EDA) software, and semiconductor manufacturing equipment (SME); **(2)** domestic chip production or access to produced chips; **(3)** domestic semiconductor workforce; and **(4)** state support for the semiconductor industry (subsidies).

- Analysis:

Based on current metrics and projected trend lines, we assess semiconductors to be a **contested space** with a **direction toward U.S. advantage**.

First, the United States leads in multiple inputs to the production process. U.S.-based firms are global leaders in chip design, with advantages across both IP cores and EDA software.³¹⁸ Currently, three U.S. firms dominate the global market for EDA software.³¹⁹ China, however, has identified EDA software as a potential choke point and is directing significant resources to develop its own domestic alternatives to avoid U.S. export controls.³²⁰ Additionally, China's

³¹⁴ Qingling Zhu, et al., [Quantum Computational Advantage via 60-Qubit 24-Cycle Random Circuit Sampling](#), ArXiv (2021).

³¹⁵ Chinese Scientists Develop New Quantum Computer with 113 Detected Photons, Chinese Academy of Sciences (2021).

³¹⁶ Charles Choi, [Two of World's Biggest Quantum Computers Made in China](#), IEEE Spectrum (2021).

³¹⁷ Access across all nodes entails access to both leading edge and legacy chips. See David Sanger, [China Has Leapfrogged the U.S. in Key Technologies. Can a New Law Help?](#), New York Times (2022); James Lewis, [Strengthening a Transnational Semiconductor Industry](#), Center for Security & International Studies at 5 (2022).

³¹⁸ Semiconductor Industry Association, [2021 State of the U.S. Semiconductor Industry](#), at 16 (2021); Rick Switzer, U.S. National Security Implications of Microelectronics Supply Chain Concentrations in Taiwan, South Korea and the People's Republic of China, Office of Commercial and Economic Analysis Occasional White Paper at 2 (2019).

³¹⁹ Steve Blank, [The Semiconductor Industry](#), Gordian Knot Center at slide 43 (2021).

³²⁰ Ben Murphy, [Chokepoints: China's Self-Identified Strategic Technology Import Dependencies](#), Center for Security and Emerging Technology at 6-9 (2022); Eleanor Olcott & Anna Gross, [US 'Blockade' Set to Turbocharge Chinese Chip Development](#), Financial Times (2022).

ecosystem is more favorable to cultivating start-up chip firms that may leapfrog current chip design leaders.³²¹ On SME, China lags behind in the ability to produce the equipment that makes the chips themselves. China remains dependent on foreign entities for equipment for creating leading edge nodes.³²² Firms based in American allies and partners – particularly Japan, the Netherlands, and Taiwan – remain the global leaders.³²³ For instance, Dutch firm ASML is an essential actor for fabrication equipment for advanced chips under 10 *nm*.³²⁴ Together, these inputs provide acute choke points that offer American advantage.³²⁵ The United States took significant steps to exercise that leverage in October 2022, introducing sweeping export controls restricting PRC access to advanced computing semiconductors and expanded U.S. controls on components destined for China’s supercomputer and semiconductor manufacturing sectors.³²⁶ The implications of those controls have only begun to become apparent.

Second, regarding chip production, both Washington and Beijing are dependent on increasingly vulnerable international supply chains. As of 2020, America domestically produced 12 percent of the global market compared to China’s 15 percent.³²⁷ The production differential is anticipated to grow by 2030, when America is projected to produce 10 percent of the global market against 24 percent from China.³²⁸ Currently both the United States and China rely on foreign suppliers for chip production.³²⁹ TSMC produces 92 percent of the advanced semiconductors designed by U.S.-based firms.³³⁰ China relies on Taiwan for roughly 70 percent of its total chip needs.³³¹

³²¹ Dylan Patel, [Why America Will Lose Semiconductors – Tangible Bi-Partisan Solutions for Solving a National Security Crisis](#), SemiAnalysis (2022); [Letter from the President’s Council of Advisors on Science and Technology \(PCAST\)](#), at 2 (2022).

³²² Steve Blank, [The Semiconductor Industry](#), Gordian Knot Center at slide 45 (2021).

³²³ James Lewis, [Strengthening a Transnational Semiconductor Industry](#), Center for Strategic and International Studies at 1, 4 (2022).

³²⁴ Richard Cronin, [Semiconductors and Taiwan’s “Silicon Shield”](#), Stimson Center (2022).

³²⁵ Chris Miller, [The Chip War](#), Scribner Press at 305-25 (2022).

³²⁶ See [Commerce Implements New Export Controls on Advanced Computing and Semiconductor Manufacturing Items to the People’s Republic of China](#), U.S. Department of Commerce, Bureau of Industry and Security (2022); Ana Swanson, [Biden Administration Clamps Down on China’s Access to Chip Technology](#), New York Times (2022). The Biden Administration imposed new restrictions on specific PRC firms, including 1) the addition of 31 PRC firms to the Department of Commerce’s Unverified List, paving the way to their potential inclusion on the Commerce Entity List (EL); 2) extending the scope of Foreign Direct Product Rule to 28 PRC entities already included on the EL, which would further constrain their ability to acquire U.S. technology; and 3) restriction on specific activities of U.S. persons conducting activities that would support the development of chip manufacturing plants inside China. For further discussion, see [Restoring the Sources of Techno-Economic Advantage](#), Special Competitive Studies Project at 56-58 (2022).

³²⁷ Antonio Varas, et al., [Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing](#), Boston Consulting Group and Semiconductor Industry Association at 7 (2020).

³²⁸ Antonio Varas, et al., [Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing](#), Boston Consulting Group and Semiconductor Industry Association at 7 (2020).

³²⁹ Rick Switzer, U.S. National Security Implications of Microelectronics Supply Chain Concentrations in Taiwan, South Korea and the People’s Republic of China, Office of Commercial and Economic Analysis Occasional White Paper at 2 (2019).

³³⁰ Richard Cronin, [Semiconductors and Taiwan’s “Silicon Shield.”](#) Stimson Center (2022).

³³¹ Richard Cronin, [Semiconductors and Taiwan’s “Silicon Shield.”](#) Stimson Center (2022).

Taiwan-based TSMC and South Korea-based Samsung currently lead the world in *4nm* and *3nm* chip development, though U.S.-based Intel is scheduled to ramp up *4nm* production later in 2022 in addition to launching *2nm* and *1.8nm* production in 2024, ahead of both Samsung and TSMC.³³² China is positioning itself to lead in the production of legacy nodes, planning to build 31 new fabs by 2024.³³³ However, U.S.-based foundries are slated for a significant boost. Five foundries – GlobalFoundries, Intel, Samsung Foundry, TSMC, and Texas Instruments – are investing in new U.S.-based facilities, with Intel alone scheduled to open two to three facilities producing chips at or below *2nm* by 2025.³³⁴ Additionally, China possesses a key advantage in assembly, packaging and testing, benefiting from its role as a “global epicenter of finished consumer electronics production.”³³⁵ Today, the United States has not more than 5 percent – and in some subcases none – of the world’s capability for outsourced assembly, testing, and packaging (OSAT).³³⁶ As of 2019, the United States was “almost completely dependent upon Taiwan and China to assemble products like servers, produce printed circuit boards (PCBs), manufacture more than 50 percent of U.S.-branded integrated circuits (IC), and conduct virtually all IC testing and packaging.”³³⁷ Notably, the U.S. global production share of PCBs has fallen to approximately four percent, while the PRC possesses over 50 percent.³³⁸

Third, as the United States and China work to build out their domestic chips industries, each requires an educated and experienced workforce. The United States must overcome a shortage of as many as 90,000 chip workers to fully capitalize on the CHIPS and Science Act-based expansion.³³⁹ These workers range from “PhDs in materials sciences and electrical engineering” to software designers and factory machine operators.³⁴⁰ China is estimated to need to close a

³³² Steve Blank, [The Semiconductor Industry](#), at Slide 32 (2021); [Intel Technology Roadmaps and Milestones](#), Intel NewsRoom (2022). SMIC was reported to reach the 7NM level in the summer of 2022; however, it still must successfully scale development at that new level. See Max Cherney, [Experts Raise Eyebrows at Claims China has Successfully Deployed Advanced Chipmaking Technology at Scale](#), Protocol (2022).

³³³ Dan Strumpf & Liza Lin, [China Chases Chip-Factory Dominance—and Global Clout](#), Wall Street Journal (2022).

³³⁴ Anton Shilov, [U.S. Semiconductor Renaissance: All the Upcoming Fabs](#), Tom’s Hardware (2022).

³³⁵ Rick Switzer, U.S. National Security Implications of Microelectronics Supply Chain Concentrations in Taiwan, South Korea and the People’s Republic of China, Office of Commercial and Economic Analysis Occasional White Paper at 8 (2019).

³³⁶ OSAT estimates vary based on specific segments (e.g. consumer versus IT infrastructure). Sujai Shivakumar and Charles Wessner place the figure at less than 5% of the global total. Sujai Shivakumar & Charles Wessner, [Semiconductors and National Defense: What Are the Stakes?](#), Center for Strategic and International Studies (2022). John VerWey notes that in advanced packaging alone, “North America’s share of global packaging capacity is only 3 percent.” John VerWey, [Re-Shoring Advanced Semiconductor Packaging: Innovation, Supply Chain Security, and U.S. Leadership in the Semiconductor Industry](#), Center for Security and Emerging Technology at 17 (2022).

³³⁷ Rick Switzer, U.S. National Security Implications of Microelectronics Supply Chain Concentrations in Taiwan, South Korea and the People’s Republic of China, Office of Commercial and Economic Analysis Occasional White Paper at 3 (2019).

³³⁸ Joseph O’Neil, [Leadership Lost?: Rebuilding the U.S. Electronics Supply Chain](#), IPC at 4 (2022).

³³⁹ Will Hunt, [Reshoring Chipmaking Capacity Requires High-Skilled Foreign Talent](#), Center for Security and Emerging Technology at 1 (2022); Stephanie Yang, [Chip Makers Contend for Talent as Industry Faces Labor Shortage](#), Wall Street Journal (2022).

³⁴⁰ Sujai Shivakumar, et al., [Reshoring Semiconductor Manufacturing: Addressing the Workforce Challenge](#), Center for Strategic and International Studies at 2 (2022).

gap of 300,000 engineers.³⁴¹ Of the two, the United States is “comparatively well positioned . . . if it can make effective use of its assets and resources.”³⁴² Already the CHIPS Act allocates \$200 million over five years for workforce development.³⁴³ American universities and private industry also are stepping up as partners to offer new education programs.³⁴⁴ However, the Commerce Department has estimated that up to \$8 billion in total investment may be needed to solve U.S. semiconductor workforce challenges.³⁴⁵ To fully address the shortage, the United States must find a resolution to its immigration challenge; “[a]pproximately 40 percent of high-skilled semiconductor workers in the United States were born abroad.”³⁴⁶ America needs to retain these workers; U.S. industry cannot meet its needs in the near-term by relying only on domestic workforce development.³⁴⁷ China, conversely, has struggled to attract foreign talent as a means of closing its domestic workforce gap.³⁴⁸

Fourth, China has led in domestic subsidies supporting the semiconductor industry. From 2014 to 2022 China is estimated to have “allocated close to \$200 billion in funding for IC capital expenditure.”³⁴⁹ The PRC’s Made in China 2025 Plan “committed \$120 billion to shore up domestic semiconductor manufacturing.”³⁵⁰ Those subsidies are significant. Left to the market alone, the United States has more natural private capital in this space.³⁵¹ America, however, has begun to offer state support with the CHIPS Act, providing a belated \$39 billion in manufacturing incentives

³⁴¹ Christopher Thomas, [Lagging But Motivated: The State of China’s Semiconductor Industry](#), Brookings Tech Stream (2021).

³⁴² Sujai Shivakumar, et al., [Reshoring Semiconductor Manufacturing: Addressing the Workforce Challenge](#), Center for Strategic and International Studies at 3 (2022).

³⁴³ [CHIPS Act Funding Sets Semiconductor Initiatives Into Motion](#), American Institute of Physics (2022).

³⁴⁴ Sujai Shivakumar, et al., [Reshoring Semiconductor Manufacturing: Addressing the Workforce Challenge](#), Center for Strategic and International Studies at 4 (2022) (discussing U.S. research universities and community colleges). For examples of university and industry action, see [Nearly \\$11M in Additional DOD Funds Expands Purdue-led Microelectronics Workforce Program](#), Purdue University (last accessed 2022); Michael Miller, [Intel Awards UC Grant for Workforce Development](#), University of Cincinnati (2022).

³⁴⁵ [CHIPS for America: A Strategy for the CHIPS for America Fund](#), U.S. Department of Commerce and National Institute of Standards and Technology at 12 (2022).

³⁴⁶ Will Hunt & Remco Zwetsloot, [The Chipmakers: U.S. Strengths and Priorities for the High-End Semiconductor Workforce](#), Center for Security and Emerging Technology at 4 (2020).

³⁴⁷ Meredith Roaten, [CHIPS Act Gives Hope to U.S. Semiconductor Industry](#), National Defense Magazine (2022) (quoting Megan Lamberth, Center for a New American Security).

³⁴⁸ Che Pan, [China’s Semiconductor Industry Faces a Growing Talent Shortage as Beijing Aims for Global Dominance in Chip Manufacture](#), South China Morning Post (2021); Will Hunt & Remco Zwetsloot, [The Chipmakers: U.S. Strengths and Priorities for the High-End Semiconductor Workforce](#), Center for Security and Emerging Technology at 4 (2020).

³⁴⁹ Rick Switzer, U.S. National Security Implications of Microelectronics Supply Chain Concentrations in Taiwan, South Korea and the People’s Republic of China, Office of Commercial and Economic Analysis Occasional White Paper at 8 (2019).

³⁵⁰ Lori Ioannou, [A Brewing U.S.–China Tech Cold War Rattles the Semiconductor Industry](#), CNBC (2020).

³⁵¹ Christopher Thomas, [Lagging But Motivated: The State of China’s Semiconductor Industry](#), Brookings Institution (2021) (“Prior to the last half-decade, China spent more than 30 years and tens of billions of dollars to build a domestic semiconductor industry, showering its national champions with resources to compete with Western companies.”).

to help level the playing field.³⁵² Consequently, if that funding is successful in unlocking greater private investment, it could help shore up the U.S. position.

Category: Convergence

Advanced Manufacturing

Assessment:	Contested
Direction:	Trend PRC

Confidence Interval:	Moderate
Confidence Interval:	Low

- Metric:

As a still emergent field, even defining “advanced manufacturing” can be challenging. The United States and China speak different technical languages around advanced manufacturing, complicating identification of standards for measurement.³⁵³ Likewise, measurement by proxy is challenging. Advanced manufacturing sits at the convergence of multiple technologies and can involve a number of elements, but each is not essential to every advanced manufacturing application.³⁵⁴ Given available data, we look to six factors to assess advanced manufacturing advantage: A country’s (1) relevant workforce; (2) “robotics density” as a measure of a “country’s level of industrial automation”,³⁵⁵ (3) secure access to microelectronics; (4) industry use of advanced networks, like 5G systems; and (5) value-added output.

- Analysis:

Based on current metrics and projected trend lines, we assess advanced manufacturing to be a **contested space** with a **direction toward PRC advantage**.

³⁵² [Fact Sheet: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China](#), The White House (2022).

³⁵³ For instance, differing terminology complicates efforts to measure advantage by publications, as the United States refers to “smart manufacturing” where China employs “intelligent manufacturing,” concepts that largely, but not entirely, overlap. Xudong Fang, et al., [Smart Manufacturing and Intelligent Manufacturing: A Comparative Review](#), *Engineering* at 743 (2021).

³⁵⁴ Advanced manufacturing “is being driven by the advent and maturation of many technologies, including: high-performance computing (HPC)-powered computer aided design (CAD) and engineering (CAE) software; cloud computing; the Internet of Things; advanced sensor technologies; 3D printing; industrial robotics; data analytics; machine learning; and wireless connectivity that better enables machine-to-machine (M2M) communications.” Stephen Ezell, [Why Manufacturing Digitalization Matters and How Countries Are Supporting It](#), Information Technology & Innovation Foundation at 2 (2018). Companies can use such tools across a range of needs from product design and production to machine maintenance and inventory/supply chain management. Robert Atkinson & Stephen Ezell, [The Manufacturing Evolution: How AI Will Transform Manufacturing & the Workforce of the Future](#), MAPI Foundation at 18-19 (2019). See also Xudong Fang, et al., [Smart Manufacturing and Intelligent Manufacturing: A Comparative Review](#), *Engineering* at 746-48 (2021); Jost Wübbeke, et al., [Made in China 2025: The Making of a High-tech Superpower and Consequences for Industrial Countries](#), *MERICS* at 13 (2016).

³⁵⁵ Emily Jin, [Smart Manufacturing: A Linchpin in China’s Industrial Policy](#), *Lawfare* (2022).

First, concerning a country's relevant workforce, an advanced manufacturing workforce requires both workers with traditional skilled manufacturing expertise and those with "a high level of preparation in science, technology, engineering, and mathematics."³⁵⁶ Both the United States and China are struggling with shortages in traditional skilled workers, such as machinists.³⁵⁷ Deloitte has found that "U.S. manufacturing is expected to have 2.1 million unfilled jobs by 2030."³⁵⁸ China's Ministry of Education estimates an even bleaker 30 million worker shortage by 2025.³⁵⁹ Regarding the science and technology workforce, much of the conversation has focused on U.S.-PRC comparisons at the PhD-level, where China is outpacing the United States in producing STEM PhDs,³⁶⁰ but China has also overtaken the United States in scientific bachelor's degrees awarded.³⁶¹ Both the United States and China are struggling with regard to traditional skilled workers,³⁶² however China is producing a greater number, per capita, of necessary S&T workers to support its transition to advanced manufacturing.³⁶³

Second, regarding robotics density, the United States still leads China, ranked seventh in the world to China's ninth.³⁶⁴ As of 2021, China possessed 246 robots installed per 10,000 employees, while the United States possessed 255 units.³⁶⁵ Nevertheless, the pace of PRC adoption markedly

³⁵⁶ [Strategy for American Leadership in Advanced Manufacturing](#), U.S. National Science and Technology Council, at 6 (2018).

³⁵⁷ See Paul Wellener, et al., [Creating Pathways for Tomorrow's Workforce Today: Beyond Reskilling in Manufacturing](#), Deloitte (2021) (describing the U.S. shortage); Chris Bentley, [U.S. Manufacturers Can't Find Enough Skilled Workers To Fill Open Jobs](#), WBUR (2021) (describing the U.S. shortage); Evelyn Cheng, [China Reports a Growing Shortage of Factory Workers](#), CNBC (2021) (describing China's shortage).

³⁵⁸ Paul Wellener, et al., [Creating Pathways for Tomorrow's Workforce Today: Beyond Reskilling in Manufacturing](#), Deloitte (2021).

³⁵⁹ Mia Nulimaimaiti, [China's Factories Are Wrestling with Labour Shortages. Age-old Prejudice Partly Explains Why](#), South China Morning Post (2022) (citing Ministry of Education figures).

³⁶⁰ See Remco Zwetsloot, et al., [China is Fast Outpacing U.S. STEM PhD Growth](#), Center for Security and Emerging Technology (2021).

³⁶¹ Joseph Kannarkat & Norman Augustine, [One Lesson the U.S. Can Learn from China to Improve its Competitiveness in Technology Development](#), Brookings Tech Stream (2021).

³⁶² Based on 2020 figures, U.S. universities conferred science or engineering bachelor's degrees at a per capita rate of 60 per 100,000 persons compared to China's 98 per 100,000 persons. For figures on degrees awarded, see Handel Jones & David Goldman, [US-China AI Rivalry a Tale of Two Talents](#), Asia Times (2022). For population figures, see [World Bank Open Data](#), World Bank (last accessed 2022). And, as of 2020, an estimated 25 percent of advanced manufacturing employment required a four-year college degree, with a majority of the remaining 75 percent "requir[ing] at least one year of postsecondary education in technology." Jeff Ryder, [Advanced Manufacturing: Industry Emphasis on Skills, Not Degrees](#), Working Nation (2020) (quoting Mike Molnar, director of NIST's Office of Advanced Manufacturing). Advanced manufacturing has given rise to at least 165 new job descriptions in the manufacturing sector, many requiring advanced education or training. Robert Atkinson & Stephen Ezell, [The Manufacturing Evolution: How AI Will Transform Manufacturing & the Workforce of the Future](#), MAPI Foundation at 27 (2019).

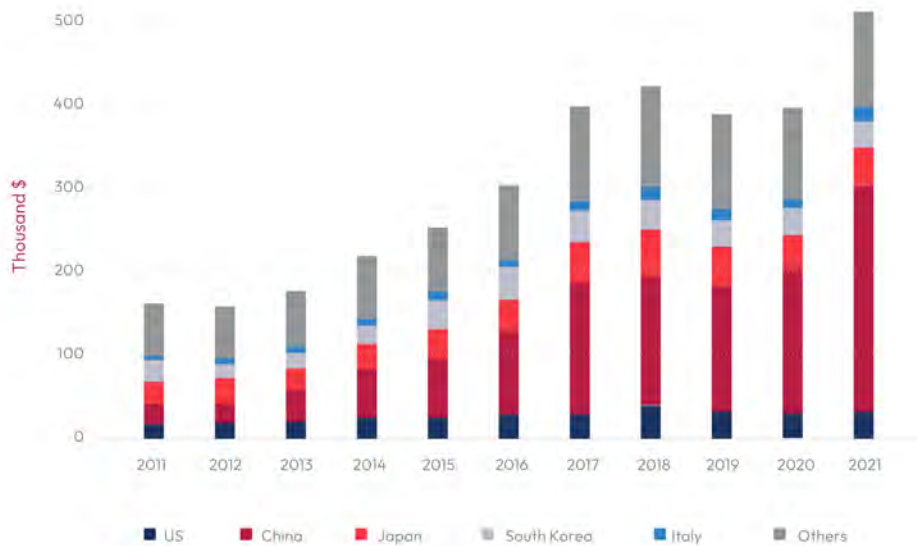
³⁶³ That figure should not belie the challenge China confronts in educating and training its absolute workforce for the advanced manufacturing field. "A staggering 70 percent of China's workforce doesn't have a high school degree, yet the jobs that complement advanced manufacturing require higher education levels." Isabella Borshoff, [China's Bot Boom](#), The Wire China (2022).

³⁶⁴ Robotics density tracks the "the degree of automation adoption in the manufacturing industry around the world." [Robot Density Nearly Doubled Globally](#), International Federation of Robotics (2021).

³⁶⁵ [Robot Density Nearly Doubled Globally](#), International Federation of Robotics (2021).

exceeds that of the United States.³⁶⁶ China has nearly reached parity with the United States despite starting in 2015 with 49 units, compared to the United States' 176 units.³⁶⁷ Thus, China is automating its manufacturing sector at a much higher rate.³⁶⁸ The United States, conversely, has been deploying robotic systems at a much lower rate when accounting for wages.³⁶⁹ This lopsided trend is likely to continue as China has prioritized robotics in its Made in China 2025 Plan, which is supported by national and provincial level subsidies.³⁷⁰

Annual Number of Industrial Robot Installations³⁷¹



Third and fourth, we consider the other key technologies discussed in this analysis on which advanced manufacturing relies. For instance, advanced manufacturing tools that rely on the IoT depend on available and affordable supplies of semiconductors and 5G.³⁷² Thus, the fact that semiconductors are contested and China possesses an advantage in 5G, respectively, casts a

³⁶⁶ Notably, China remains heavily reliant on Japanese companies. Jason Douglas, [China's Factories Accelerate Robotics Push as Workforce Shrinks](#), Wall Street Journal (2022). However, China is seeking, and currently working toward, a domestic production capacity and localized supply chain. Isabella Borshoff, [China's Bot Boom](#), The Wire China (2022).

³⁶⁷ [Robot Density Nearly Doubled Globally](#), International Federation of Robotics (2021).

³⁶⁸ Christopher Mims, [Meet the Army of Robots Coming to Fill In for Scarce Workers](#), Wall Street Journal (2022). Demographic necessities are spurring the PRC's rapid automation drive. See *Welcome to the Machine: A Comparative Assessment of the USA and China to 2035 Focusing on the Role of Technology in the Economy*, Fathom Financial Consulting Limited (2022) (*SCSP-commissioned work product*).

³⁶⁹ Robert Atkinson, [Which Nations Really Lead in Industrial Robot Adoption?](#), Information & Technology Innovation Foundation at 4-5 (2018).

³⁷⁰ Isabella Borshoff, [China's Bot Boom](#), The Wire China (2022).

³⁷¹ Christopher Mims, [Meet the Army of Robots Coming to Fill In for Scarce Workers](#), Wall Street Journal (2022).

³⁷² [Strategy for American Leadership in Advanced Manufacturing](#), National Science and Technology Council at 14-15 (2018).

shadow on this technology area³⁷³ and enhances China’s position.³⁷⁴ This determination is reinforced by the World Economic Forum’s Global Lighthouse Network, which identifies smart factories around the world.³⁷⁵ As of March 2022, 36 qualifying factories are in China, compared to 9 in America.³⁷⁶

Fifth, we examine comparative industrial output. Here, “America’s relative performance in advanced industries has been weak over the last two decades.”³⁷⁷ When controlled for U.S. leadership in IT and information services, comparing 1995 and 2018 reveals “America’s relative share of advanced industries declined by nearly 16 percentage points . . . [indicating] the share of the U.S. economy made up by these industries is almost 20 percent less than the global average.”³⁷⁸ Conversely, looking at 2018 data, China enjoyed advanced industry concentrations 34 percent higher than that same global average.³⁷⁹

Commercial Drones

Assessment:	PRC-Lead
Direction:	Trend PRC

Confidence Interval:	High
Confidence Interval:	High

- Metric:

While a vibrant commercial drone sector is a source of economic benefit for a country, in an international competition it is also a matter of intelligence collection, providing a platform that can be used for military, politically coercive, and transnationally repressive ends.³⁸⁰ When governments, public utilities, or large-scale private actors use drones these systems can turn into a data collection platform, transmitting a wealth of information to company-maintained data centers.³⁸¹ We look to global market share as a proxy measure of how likely a drone can serve as an intelligence and data vulnerability.

³⁷³ For more on this, see the section regarding semiconductors within this appendix.

³⁷⁴ 5G adoption is particularly important given the role of networks of sensors and the industrial Internet of Things (IIOT) that accelerate advanced manufacturing. Stephen Ezell, [Why Manufacturing Digitalization Matters and How Countries Are Supporting It](#), Information Technology & Innovation Foundation at 2 (2018).

³⁷⁵ See [Global Lighthouse Network](#), World Economic Forum (last accessed 2022).

³⁷⁶ [The Global Lighthouse Network Playbook for Responsible Industry Transformation](#), World Economic Forum and McKinsey at 7-8 (2022).

³⁷⁷ Robert Atkinson, [The Hamilton Index: Assessing National Performance in the Competition for Advanced Industries](#), Information Technology & Innovation Foundation at 6 (2022).

³⁷⁸ Robert Atkinson, [The Hamilton Index: Assessing National Performance in the Competition for Advanced Industries](#), Information Technology & Innovation Foundation at 6-7 (2022).

³⁷⁹ Robert Atkinson, [The Hamilton Index: Assessing National Performance in the Competition for Advanced Industries](#), Information Technology & Innovation Foundation at 7 (2022).

³⁸⁰ Cate Cadell, [Drone Company DJI Obscured Ties to Chinese State Funding, Documents Show](#), Washington Post (2022); Press Release, [Department Statement on DJI Systems](#), U.S. Department of Defense (2021); Lachlan Markay, [Scoop: U.S. Government Buying Risky Chinese Drones](#), Axios (2021).

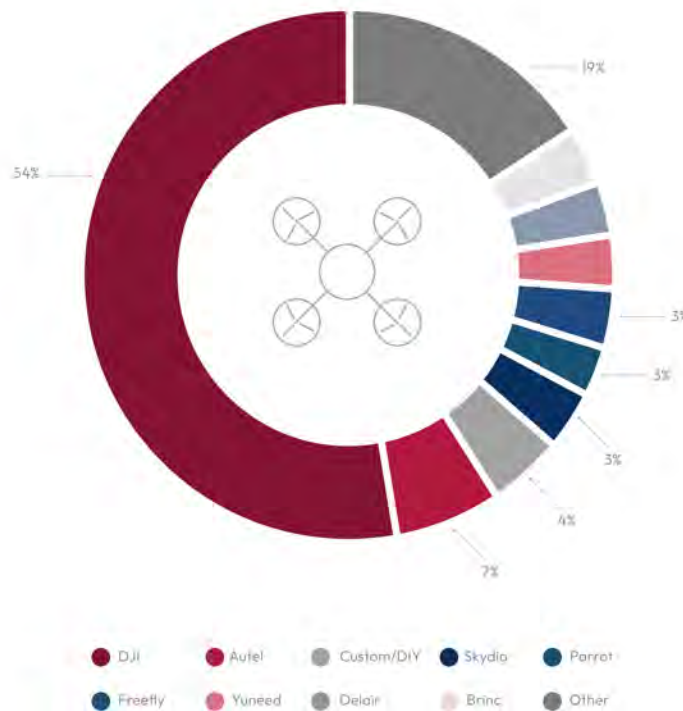
³⁸¹ Bruce Einhorn & Todd Shields, [Drones Take Center Stage in U.S.-China War on Data Harvesting](#), Bloomberg (2021).

- Analysis:

Based on current metrics and projected trend lines, we assess **PRC leadership** in commercial drones with a continued **direction toward PRC advantage**.

As of 2021, PRC-based firm DJI held 50–54 percent of the global commercial drone market, while the next largest firm by market share – Autel, also a PRC-based firm – commands only 7–9 percent of the global market.³⁸² Comparatively in 2021, the leading U.S.-based firm – Skydio – possessed only 3 percent market share.³⁸³ Even collectively, U.S.-based firms reflected only 16 percent of the global market.³⁸⁴ DJI established and maintained its dominant position through steep price reductions, as evidenced by the case of pushing 3D Robotics out of drone hardware in 2016 by dropping its price 70 percent.³⁸⁵

Commercial Drone Brand Market Share³⁸⁶



³⁸² Demetri Sevastopulo, [Chinese Drone Maker Lobbies to Defeat US National Security Ban](#), Financial Times (2022).

³⁸³ Gina Chon, [DJI is a More Elusive U.S. Target than Huawei](#), Reuters (2021).

³⁸⁴ Ishveena Singh, [DroneAnalyst Report Reveals Dramatic Drop in DJI's Commercial Drone Market Share](#), DroneDJ (2021) (citing data from market analysis firm DroneAnalyst).

³⁸⁵ April Glaser, [DJI is Running Away with the Drone Market](#), Vox (2017).

³⁸⁶ Ishveena Singh, [DroneAnalyst Report Reveals Dramatic Drop in DJI's Commercial Drone Market Share](#), DroneDJ (2021).

Looking within the U.S. market DJI possessed almost 80 percent of the commercial market, with U.S. federal, state, and local agencies – including law enforcement in New York, Boston, and over 900 public safety agencies – relying on DJI drones.³⁸⁷ A recent push by the federal government has sought to reduce reliance on DJI, but with only partial success to date.³⁸⁸ Furthermore, multiple U.S. allies – including the EU – are not yet convinced³⁸⁹ of American concerns over PRC-made drones, though some private sector actors are applying pressure where governments are not.³⁹⁰

³⁸⁷ Gina Chon, [DJI is a More Elusive U.S. Target than Huawei](#), Reuters (2021).

³⁸⁸ Lachlan Markay, [Scoop: U.S. Government Buying Risky Chinese Drones](#), Axios (2021).

³⁸⁹ Saim Saeed, [Europe Buys Chinese Drones, Even as US Expresses Data Concerns](#), Politico EU (2019).

³⁹⁰ Ishveena Singh, [DJI Clarifies its Position on War After German Retailer Suspends Drone Sales](#), DroneDJ (2022).

Appendix C: Assessing Four Public-Private Models for Enhancing Competitiveness

America needs an organizational entity more capable of actively harnessing the nation's latent potential. Multiple proposals exist for organizing the U.S. ecosystem for the unfolding techno-economic competition.³⁹¹ To refine that debate, we considered four potential models for action: (1) reform existing White House-based institutions; (2) establish new entities within government, a joint Technology Competitiveness Council and Office for Global Competition Analysis; (3) charter a government-backed nonprofit entity that sits adjacent to government; and (4) create a private, philanthropically funded nonprofit to serve as an institutional hub.

Reform Existing Institutions

The first path would be to reform existing institutions to make them fit a contemporary purpose. Updates to the NSC and OSTP would include:

- *Bolstering NSC focus on emerging technologies in operations and strategic planning:* The Biden Administration's creation of an NSC Directorate for National Security and Technology should be maintained across administrations.³⁹² Simultaneously, the Directorate for Strategic Planning should add 1-2 directors for technology planning.³⁹³
- *Increasing dual-hatting of NSC and OSTP staff to further integration:* Increased dual-hatting at the staff level, including directors in the National Security and Technology and Strategic Planning Directorates, could better position OSTP to bring expertise to inform and support the NSC policy process. The OSTP director also should be permanently designated a full NSC member.³⁹⁴
- *Empowering a Deputy National Security Advisor (DNSA) for Emerging Technology:* A DNSA focused first and foremost on emerging technology could oversee a cross-cutting

³⁹¹ See Erica Fuchs, [Building the Analytical Capacity to Support Critical Technology Strategy](#), Brookings: The Hamilton Project at 17 (2022); Loren DeJonge Schulman & Ainikki Riikonen, [Trust the Process: National Technology Strategy Development, Implementation, and Monitoring and Evaluation](#), Center for a New American Security at 5 (2021); Robert Atkinson, [Why America Needs a National Competitiveness Council](#), Information Technology & Innovation Foundation (2021); Robert Atkinson, [Why the United States Needs a National Advanced Industry and Technology Agency](#), Information Technology & Innovation Foundation (2021).

³⁹² Daniel Lippman, et al., [Biden's Beefed-up NSC](#), Politico (2021); [Asymmetric Competition: A Strategy for China & Technology Actionable Insights for American Leadership](#), China Study Group at 28 (2020).

³⁹³ [Asymmetric Competition: A Strategy for China & Technology Actionable Insights for American Leadership](#), China Study Group at 28 (2020).

³⁹⁴ See Christopher Chyba & Ethan Magistro, [The President's Science Advisor Should be a Full Member of the National Security Council and its Principals Committee](#), War on the Rocks (2020).

staff that would draw on NSC, OSTP, and the National Economic Council (NEC) personnel to provide a comprehensive perspective.³⁹⁵

- *Establishing a cross-institutional secretariat supporting the DNSA:* A limited executive secretariat drawing rotating staff from the NSC, OSTP, and NEC would support the new DNSA with a wider competitive lens.³⁹⁶

Assessed along the eight elements, reforming current institutions is a **moderately effective model**.

1. *Access to Senior Public Leaders:* The reform approach capitalizes on advantages already present in the NSC-based system, including tremendous access to public leaders in the President and Cabinet secretaries. However, that close proximity also could inhibit long-term technological strategy as the “urgent crowds out the important.”
2. *Capacity to Routinely Engage Private Sector Leaders:* Direct access to senior policymakers and policy levers provides traditional institutions robust credibility with the private sector. However, by the inherent nature of the U.S. government, the White House is restricted in ways that encumber routine private sector engagement. Furthermore, that political proximity could impact the willingness of nongovernmental actors to engage due to political perceptions.
3. *A Competitive Lens:* A comprehensive competitive lens for the current moment cuts across domains traditionally siloed to the NSC, OSTP, and NEC. ADNSA could spearhead coordination across those three staffs to bring the respective perspectives together to combine to a sum greater than the individual parts. Already two Presidents have embraced a broader conception of national security that may be necessary to achieve the necessary scope of the competitive lens.³⁹⁷ However, this approach still requires personnel placing that more holistic vision above the institutional equities of their respective home staffs.

³⁹⁵ Loren DeJonge Schulman & Ainikki Riikonen, [Trust the Process: National Technology Strategy Development, Implementation, and Monitoring and Evaluation](#), Center for a New American Security at 5 (2021); Brendan McCord & Zoe Weinberg, [Emerging Technology & The Future of the National Security Council](#) at 19 (2020). The Biden Administration created a Deputy National Security Advisor for Cyber and Emerging Technology position in 2021. See [Statement by Deputy National Security Advisor for Cyber and Emerging Technology Anne Neuberger on President Biden’s Cyber Executive Order](#), The White House (2022). The central importance of emerging technologies merits a DNSA focused entirely on emerging technology.

³⁹⁶ Loren DeJonge Schulman & Ainikki Riikonen, [Trust the Process: National Technology Strategy Development, Implementation, and Monitoring and Evaluation](#), Center for a New American Security at 16-17 (2021).

³⁹⁷ See [National Security Strategy](#), The White House (2022); [National Security Strategy](#), The White House (2017).

4. *Broad Technology Scope:* If the proposed enhanced coordination is successful, the President would need not alter or expand the scopes of the constituent staffs. OSTP, supplemented by STPI, would provide a broad scientific base to support coordinated operations. However, that vision depends on OSTP consistently embracing the competitive lens to prevent new gaps from emerging.
5. *Independence in Analysis:* The White House lacks a capacity for long-term, independent technology analysis. Horizon-scanning functions would have to be located in a separate venue, such as STPI, requiring a significant investment and shift in the sense of mission toward science and technologies relevant to national security and competitiveness.³⁹⁸
6. *Accountable Action Arm:* A reformed process around a DNSA would offer a clear interagency lead for implementing TAPs. The NSC has a strong record of wrestling the bureaucracy to implement the President’s agenda³⁹⁹ and is well situated to marshaling the federal agencies and pull on multiple policy levers to align the U.S. ecosystem. However, the realities of NSC work suggest directors would be pulled into more near-term projects and crises, leaving them less time for those longer-term issues.
7. *Longevity and Continuity:* Updating the NSC structure and increasing NSC-OSTP coordination, likely by executive order, offers little inherent longevity. Presidents can change structures even within a single administration.⁴⁰⁰ Additionally, high personnel turnover would undermine the ability of a national mission manager to shepherd a long-term project.
8. *Signal Priority:* While reforming existing institutions would activate fewer antibodies in the system than creating a new entity, it may not be a sufficient signal to the U.S. Government, private sector, and general public as to the competition’s stakes.

³⁹⁸ As of 2020, STPI’s budget was \$4.74 million. This is likely insufficient to do the horizon scanning function necessary. John F. Sargent Jr. & Dana A. Shea, [Office of Science and Technology Policy \(OSTP\): History and Overview](#), Congressional Research Service at 9-10, 23 (2020).

³⁹⁹ See Henry Kelly, et al., [Flying Blind: The Rise, Fall, and Possible Resurrection of Science Policy Advice in the United States](#), Federation of American Scientists at 32 (2004) (discussing the National Security Advisor’s ability to shape information and decision flows to the President as a key ingredient in the National Security Advisor having influence over the bureaucracy; while concerning the NSTC each individual agency is able to circumvent the President’s Science Advisor).

⁴⁰⁰ See John Rollins, [The National Security Council: Background and Issues for Congress](#), Congressional Research Service at 7-8 (2022); David Rothkopf, [Running the World](#), Public Affairs at 166 (2005).

Technology Competitiveness Council & Office of Global Competition Analysis

Congress could enact the dual proposals of a Technology Competitiveness Council and an Office for Global Competition Analysis.⁴⁰¹ A joint TCC-OCA proposal would:

- *Conduct long-term technology analysis in a separate OCA:* The OCA would sit outside the White House, providing an analysis hub removed from political considerations and the crush of the urgent. OCA would draw on government and voluntarily shared private data to conduct horizon scanning to identify strategic technologies.
- *Engage with senior policymakers to receive strategic guidance in the TCC:* A select TCC staff would engage with senior policymakers to draft TAPs for identified technologies. That staff also would appoint a national mission manager to carry the TAP to conclusion.
- *Convene key private sector stakeholders at the TCC:* The TCC would gather public and private investors for alignment working groups to find self-selecting supporters of key technology missions.
- *Oversee the implementation process:* The national mission manager, either situated at or in coordination with the TCC, would monitor progress, consistently coordinate private investors, and drive any necessary regulatory updates to support the TAP.
- *Meet under the Vice President or an Assistant to the President for Technology Competitiveness:* Either the Vice President or a new assistant to the President would manage the TCC staff and oversee the national technology strategy process.⁴⁰² Having this senior champion would be important to ensure the TCC-OCA is not sidelined amidst the scrum of the policymaking process.

Assessed along the eight elements, the TCC-OCA combination is a **highly effective model**; however, neither the TCC nor OCA would be sufficient on its own.

1. *Access to Senior Public Leaders:* The TCC's White House base would allow it access to senior policy leaders. That direct tie would augment the TCC's credibility with private sector leaders in being seen as representing Presidential priorities. However, that same access could shift technology strategy-setting away from longer-term trends and toward more immediate political goals.

⁴⁰¹ See H.R. 8027, [To Establish within the Executive Office of the President a Technology Competitiveness Council](#) (2022); Courtney Albon, [Lawmakers Propose 'Technology Competitiveness Council' to Champion US Innovation](#), C4ISRNet (2022); S. 4368, [American Technology Leadership Act of 2022](#) (2022); Daniel Flatley, [Senators Wary of China's Tech Prowess Seek Competition Office](#), Bloomberg (2022).

⁴⁰² An Assistant to the President for Technology Competitiveness would sit equal to the National Security Advisor and Assistant to the President for Science and Technology.

2. *Capacity to Routinely Engage Private Sector Leaders:* The combination of the TCC and OCA provides multiple plug-in points for private sector representatives. The TCC can convene high profile leaders, particularly investors, to support critical technology missions. Simultaneously, OCA allows the government and industry to have more granular discussions of technology trends in a forum removed from the political level and insulated from regulatory action.⁴⁰³
3. *A Competitive Lens:* Congress could provide the TCC and OCA the necessary lens from the outset. There would be fewer pain points than in having to transition existing offices and personnel to embrace new missions and remits. Furthermore, adopting a competitive lens in an entity outside the NSC and OSTP avoids conflating outlooks and losing the valuable perspectives of existing offices, and avoids over-securitization of the work.⁴⁰⁴
4. *Broad Technology Scope:* Likewise, in authorizing a new pair of entities, Congress could provide as wide a technological scope as the competition demands. There would be no preconceived focus on exclusively defense technologies, as is sometimes the case with the NSC.
5. *Independence in Analysis:* OCA would provide a capacity for long-range horizon scanning that draws on multiple public and private sources of information.⁴⁰⁵ OCA would consist of a more permanent analytical staff, supplemented by detailees and nongovernmental fellows to ensure consistent information flows within government and between the public and private sectors.⁴⁰⁶ However, some private actors may be reluctant to share information with an office like the OCA, including out of concern that such data could be used in regulatory action against the private firm.⁴⁰⁷
6. *Accountable Action Arm:* The TCC staff would be clearly responsible for progress on specific technology goals. They would be able to leverage the weight of the White House to support national mission managers leading TAP implementation. As with the NSC, the

⁴⁰³ Erica Fuchs, [Building the Analytical Capacity to Support Critical Technology Strategy](#), Brookings: The Hamilton Project at 10-11 (2022) (discussing the importance of independence in analysis); [Remarks by Erica Fuchs at Reimagining Industrial Policy for the Service and Tech Sectors](#), Brookings Institution (1:09:00) (2022).

⁴⁰⁴ Erica Fuchs, [What a National Technology Strategy Is—and Why the United States Needs One](#), Issues in Science and Technology (2021); Brendan McCord & Zoe Weinberg, [Emerging Technology & The Future of the National Security Council](#) at 24 (2020).

⁴⁰⁵ See Press Release, [Bennet, Sasse, Warner Unveil Legislation to Strengthen U.S. Technology Competitiveness](#), Office of Senator Michael Bennet (2022).

⁴⁰⁶ See Erica Fuchs, [Building the Analytical Capacity to Support Critical Technology Strategy](#), Brookings: The Hamilton Project at 10-11 (2022).

⁴⁰⁷ [Remarks by Erica Fuchs at Reimagining Industrial Policy for the Service and Tech Sectors](#), Brookings Institution (1:09:00) (2022).

TCC would demonstrate senior government interest and support, as well as run a rigorous interagency process generally missing in the science and technology apparatus.⁴⁰⁸

7. *Longevity and Continuity:* A joint TCC-OCA would provide continuity in personnel that the TCC alone would lack. OCA, perhaps based in an FFRDC, would be positioned to retain personnel long-term. The TCC would have moderate longevity. A statutory foundation would best ground the entity. However, history suggests that the risk remains that the White House could still ignore or under-utilize the institution.⁴⁰⁹
8. *Signal Priority:* Creating a joint TCC-OCA would be a strong signal of the seriousness that the U.S. Government ascribes to the competition. Particularly if enacted by Congress and welcomed by the President, the TCC-OCA model would show multiple branches of government acting to address the competition and likely spur momentum elsewhere. Nonetheless, the TCC-OCA offices, particularly the former, would confront the challenge of having to assert itself in an already crowded institutional field.

Congressionally Established Nongovernmental Entity: U.S. Advanced Technology Forum

Congress could establish an independent nonprofit corporation, a U.S. Advanced Technology Forum, as a federally chartered organization sitting adjacent to the government.⁴¹⁰ USATF would:

- *Sit outside of the U.S. Government but retain governmental direction:* USATF would be an independent institution, but operate on a Congressionally-defined mission set in statute. Congress also would oversee its actions through a bipartisan appointed board of directors that includes Cabinet-level officials and a cross-section of nongovernmental experts.
- *Engage nongovernmental actors to conduct long-term technology analysis:* A Research and Analysis Division would conduct horizon scanning via collaboration with industry and academia. It would draw on data both from government agencies and shared by industry and academia.
- *Deploy internal expertise to curate technology action plans:* A Curation Division would propose TAPs to the U.S. Government and private sector. Those plans would identify

⁴⁰⁸ Henry Kelly, et al., [Flying Blind: The Rise, Fall, and Possible Resurrection of Science Policy Advice in the United States](#), Federation of American Scientists at 32 (2004).

⁴⁰⁹ As an example, despite being established by law in 1989, the National Space Council was not operational from 1993 to 2017. [National Space Council](#), The White House (last accessed 2022).

⁴¹⁰ See e.g., Pub. L. 98-525, [The United States Institute of Peace Act](#) (1984, amended 2008); Pub. L. 98-164, [A Bill to Authorize Appropriations for Fiscal Years 1984 and 1985 for the Department of State, the United States Information Agency, the Board for International Broadcasting, the Inter-American Foundation, and the Asia Foundation, to establish the National Endowment for Democracy, and for other purposes](#) (1983) (creating the National Endowment for Democracy as an independent, but federally funded, entity).

policy levers for the government and rationales for private actors to work on or invest in specific projects.

- *Convene public and private investors to put money behind missions:* A Resourcing Division would gather investors to support TAPs. USATF would share new investment opportunities, support investors self-aligning, and enable the government to hear from investors.
- *Monitor TAP implementation:* An Implementation Division would assign a national mission manager to oversee progress on a TAP. The national mission manager would facilitate continued public-private working groups and provide public status reports.

Assessed along the eight elements, USATF is a **moderately effective model**.

1. *Access to Senior Public Leaders:* While USATF would have governmental direction through its board, its access to policymakers would be uncertain. Presidents could embrace or ignore USATF with ease. Ultimately, it would be one of many nongovernmental entities competing for policymakers' attention and agreement.
2. *Capacity to Routinely Engage Private Sector Leaders:* USATF's credibility in outreach to private sector leaders would depend, in part, on its access to public leaders. Many private firms would probably be more interested in dedicating time and resources to engaging with the independent entity if they believed its recommendations were read and given weight by the government and their peers.
3. *A Competitive Lens:* Congress could create USATF with the appropriate lens. Pre-existing areas of focus or perspectives would not bind a new institution. USATF's board could provide guidance on national leadership's conception of the techno-economic competition to shape the entity's work.⁴¹¹
4. *Broad Technology Scope:* Similarly, Congress could mandate a clear but flexible mission scope that includes all technologies that USATF finds relevant to U.S. national security and national competitiveness.
5. *Independence in Analysis:* USATF would be positioned to perform rigorous independent analysis that draws on a mixture of unclassified government assessments, industry data,

⁴¹¹ See Pub. L. 98-525, [The United States Institute of Peace Act](#) (1984, amended 2008) (appointing the Secretaries of State and Defense to USIP's board).

private sector economic intelligence, and academic research.⁴¹² Additionally, governmental rotations or private sector fellowships could bring together a cross section of leading experts under one roof.

6. *Accountable Action Arm:* While USATF could draft and seek to convene investors for TAPs, it would lack authority to move public policy levers, such as coordinating regulatory shifts or directing certain funding channels.
7. *Longevity and Continuity:* Creating USATF via legislation would support a measure of resilience against momentary political winds. Likewise, its status as a nongovernmental entity would accord with providing a consistent staff focused on long-term missions and offering institutional memory.
8. *Signal Priority:* Creating USATF may signal priority depending how public leaders message and treat the new organization. For instance, presidents have supported the National Endowment for Democracy (NED) in rhetoric and budget such that it has remained an active force for almost forty years.⁴¹³

Independent Private Technology Organization

Should a government-backed model not be feasible, a privately-supported nongovernmental organization could pick up the torch. Organizationally, the organization could look quite similar to USATF. It would:

- *Center on four divisions aligned with the National Technology Strategy Process:* An independent nonprofit organization could mimic USATF’s organization, basing its work in a Research & Analysis Division, a Curation Division, a Resourcing Division, and an Implementation Division.
- *Rely on private philanthropic funding:* Rather than rely on governmental funding, the organization would require full support from private philanthropy. That support would have to be rigorously assessed to ensure objectivity in the organization’s work.

⁴¹² This collection of expertise and information would be particularly valuable as, often, much of the best technology knowledge exists in the private sector. See, e.g., Catherine McAnney, [The Need for Greater Technical Talent in the Government](#), Belfer Center on Science and International Affairs (2021).

⁴¹³ David Lowe, [History: Idea to Reality: NED at 30](#), National Endowment for Democracy (last accessed 2022) (discussing presidential support from Presidents Reagan through Obama). As a testament to the NED’s stature in promoting democracy around the globe, it was the “first group to be banned in Russia under a law against ‘undesirable’ international nongovernmental organisations” in 2015. Alex Luhn, [National Endowment for Democracy is First ‘Undesirable’ NGO Banned in Russia](#), Guardian (2015).

- *Voluntarily align with U.S. Government objectives:* Unlike the USATF model’s government mandate, the private philanthropic organization would have to self-define and act on its own conception of national security and competitiveness.

Assessed along the eight elements, a private philanthropic organization is a **less effective model**.

1. *Access to Senior Public Leaders:* A fully private organization would lack any formalized access to public leaders. It would have to regularly compete for policymakers’ attention in order to get its analysis seen and recommendations heard. A robust relationship with one administration may well not transfer to the next, risking isolation.
2. *Capacity to Routinely Engage Private Sector Leaders:* Engagement with private sector leaders would be fully possible, but would be contingent on the organization’s credibility. Private sector leaders would carefully scrutinize how influential they believe the organization to be and then calibrate their engagement. An organization that does not deliver early successes would fade rapidly.
3. *A Competitive Lens:* A new organization would be free to focus on the key intersection of national security and national competitiveness that touches on the nation’s defense capabilities, ability to conduct foreign policy, economic prosperity, and societal vibrance.
4. *Broad Technology Scope:* Similarly, the organization could cast as wide a net as it chooses in the technologies it considers relevant to national security and competitiveness.
5. *Independence in Analysis:* Already, multiple private think tanks exist that undertake research, perform strategic analysis, and convene key stakeholders.⁴¹⁴ Those institutions also offer opportunities for government and private sector personnel to temporarily join and contribute to their analysis.⁴¹⁵ However, the independence of that analysis is under constant scrutiny based on funding sources and relationships.⁴¹⁶
6. *Accountable Action Arm:* While the organization would be free to convene private investors, its limit would be public perception of its influence and success. As with USATF,

⁴¹⁴ Some do, however, question the ability of such an organization to “attract star talent from industry and academia.” Erica Fuchs, [Building the Analytical Capacity to Support Critical Technology Strategy](#), Brookings: The Hamilton Project at 17 (2022).

⁴¹⁵ Existing programs facilitate the temporary assignment of U.S. Government personnel to think tanks or academic institutions for a set period of time. See e.g., [Federal Executive Fellows 2021-2022](#), Brookings Institution (last accessed 2022); [2022-2023 Senior Fellows & Associates](#), Georgetown University Institute for the Study of Diplomacy (last accessed 2022).

⁴¹⁶ For a window into the debates and challenges in this space, see Katarzyna Jezierska & Adrienne Sörbom, [Proximity and Distance: Think Tanks Handling the Independence Paradox](#), Governance (2020).

the fully private organization would lack access to public policy levers, leaving it reliant exclusively on its convening power to move forward technology objectives.

7. *Longevity and Continuity*: A new organization has no inherent barriers to its longevity or continuity in personnel. The organization would exist as long as it is funded. It could retain staff indefinitely to provide institutional memory and consistent work on missions.
8. *Signal Priority*: The U.S. Government's failure to organize for the competition would show a lower degree of attention to the techno-economic competition. While private actors stepping forward to fill the gap would be a signal, it would not be as powerful.

Recommendation: A Hybrid Model

The four preceding models are each distinct, offering different mixtures of advantages and weaknesses. Within those models, the TCC-OCA option stands out as the leader among the eight identified elements for the ideal entity for the national technology strategy process. Yet, not all models are inherently contradictory. A combination of models may even further strengthen America's ability to compete. Pairing the TCC-OCA option with a USATF could be mutually reinforcing. For instance, private firms may be more willing to share data with a nonprofit, nongovernmental organization than directly with the government.⁴¹⁷ Thus, it would serve as a complement to the OCA. Additionally, the USATF could help carry out the national technology strategy process by serving not only as a supplemental analysis arm, but as a convener of investors at higher volumes, as well as those who are more comfortable operating at arm's length from the government.

⁴¹⁷ See [Remarks by Erica Fuchs at Reimagining Industrial Policy for the Service and Tech Sectors](#), Brookings Institution (1:09:00) (2022) (raising the data sharing concern).

Appendix D: From the Lab to the Grid: An Action Plan for U.S. Advantage in Fusion Energy

Introduction

Fusion energy could put the power of the Sun on Earth. As a clean, limitless energy source,⁴¹⁸ fusion could power the electric infrastructure of the future and help to achieve decarbonization goals.⁴¹⁹ Fusion's economic potential extends far beyond what is conceivable today.⁴²⁰ Geopolitically, it could rewire foreign energy dependencies and unlock new defense and space capabilities.⁴²¹ Secure access to fusion will be a national security imperative, and fusion leadership would be a boon to the nation.

The Decade of Fusion is Here

A fusion future can soon be realized.⁴²² Thanks to private sector efforts, a commercially-practical fusion reaction that creates more energy than it consumes⁴²³ could be achieved as soon as 2024.⁴²⁴ A race for scale and commercialization will follow. If the United States organizes, it can win this race. The next decade will determine which countries become importers versus exporters of fusion. The Biden Administration's *Bold Decadal Vision for Commercial Fusion* is a key step in the right direction.⁴²⁵ Now the nation must execute and build upon that vision to reap the economic, social, and geopolitical benefits that fusion can offer.

Guiding Policy:

The government must treat fusion as a strategic commercial endeavor rather than purely a science mission. Bringing fusion from the lab to the grid will require a series of smart business decisions: planning beyond the initial technological breakthrough; focusing ecosystem actors' on

⁴¹⁸ Boštjan Videmšek, [Nuclear Fusion Could Give the World a Limitless Source of Clean Energy. We're closer Than Ever To It](#), CNN (2022). Fusion is expected to generate four times more energy than nuclear fission and four million times more than fossil fuels. See [Making It Work](#), ITER (last accessed 2022). Fusion could also help advance other energy and climate-related technologies, such as advanced hydrogen production, water desalination, direct CO2 capture, electrofuel, and chemical production. See [Latest News](#), ITER (last accessed 2022).

⁴¹⁹ See Miklós Dietz, et al., [Will Fusion Energy Help Decarbonize the Power System?](#), McKinsey & Company (2022).

⁴²⁰ Fusion energy has been valued as a \$40T market if it replaces just 1% of global energy draw. See [Nuclear Fusion Market Could Achieve a \\$40 Trillion Valuation](#), Bloomberg Intelligence (2021).

⁴²¹ See Melanie Windridge, [The New Space Race Is Fusion Energy](#), Forbes (2020); [Written testimony of Scott Hsu before the Senate Committee on Energy and Natural Resources](#) (2022).

⁴²² Tom Wilson & Ian Bott, [Nuclear Fusion: Why the Race to Harness the Power of the Sun Just Sped Up](#), Financial Times (2021).

⁴²³ Several technological approaches are being pursued to sustain a relevant plasma energy breakeven point in which the energy output of a fusion reaction exceeds its input ($Q > 1$) for a certain amount of time, demonstrating the commercial viability of the energy source. Approaches range from the mainstream (magnetic, inertial, and magneto-inertial confinement) to the unconventional (muon-catalyzed fusion). See [The Global Fusion Industry in 2022](#), Fusion Industry Association (2022); [60 Years of Progress](#), ITER (last accessed 2022).

⁴²⁴ Haje Jan Kamps, [Helion Secures \\$2.2B to Commercialize Fusion Energy](#), TechCrunch (2021); David Chandler, [MIT-Designed Project Achieves Major Advance Toward Fusion Energy](#), MIT News (2021).

⁴²⁵ [Readout of the White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy](#), The White House (2022).

their competitive advantages; accelerating results through incentives; and cultivating fusion talent.

Action Plan Overview

With the might of the private sector, the United States can win the race for commercial fusion.⁴²⁶ A coordinated effort by the U.S. Government to fund, implement, and empower commercial fusion will unleash a new industry – centered in America – that addresses key climate and geopolitical challenges. Such an action plan should contain the following core elements:

- *Get Fusion On the Grid by 2030*
- *Empower DOE with a Commercial Fusion Mission*
- *Leverage Actors' Core Strengths*
- *Add Government Fuel Where it Will Accelerate Commercialization*
- *Determine a Basic Regulatory Framework Within the Next Year*
- *Balance Information Sharing and Intellectual Property Protection*
- *Bolster the Fusion Supply Chain*
- *Foster a Broad Base of Fusion Talent*

Diagnosis:

The private sector has accelerated decades of research in national and collaborative international labs, collectively investing more than \$5 billion in fusion's development.⁴²⁷ The United States is the hotbed of this commercial fusion activity, housing more than half of the world's 35 known fusion companies.⁴²⁸ Commercial actors have progressively shortened the timeline for demonstrating a net-positive fusion reaction to 2025, and have announced plans for fully-operational pilot facilities producing electricity by the early 2030s.⁴²⁹

Regardless of who achieves the first breakthrough, fusion will ultimately be a race for commercial scale. This demands additional innovation and scale in materials, compute, and manufacturing as well as concurrent efforts to update regulations. Advancements in AI have already enabled⁴³⁰ –

⁴²⁶ Written testimony of Bob Mumgaard before the Senate Committee on Energy & Natural Resources, [The Federal Government's Role in Supporting the Commercialization of Fusion Energy](#) (2022).

⁴²⁷ As of writing, the Fusion Industry Association reported \$4.7 billion in private investment in fusion. See [The Global Fusion Industry in 2022](#), Fusion Industry Association at 6 (2022). Since publication of the FIA report, fusion company TAE Technologies reported an additional \$250 million in funding, bringing total private investment in fusion over \$5 billion. See Timothy Gardner, [U.S. Nuclear Fusion Company TAE Raises \\$250 Million in Latest Round](#), Reuters (2022).

⁴²⁸ [New Survey of Fusion Energy Companies Throws Spotlight on Important Growing Industry](#), UK Atomic Energy Authority (2021); [The Global Fusion Industry in 2022](#), Fusion Industry Association at 7 (2022).

⁴²⁹ Haje Jan Kamps, [Helion Secures \\$2.2B to Commercialize Fusion Energy](#), TechCrunch (2021); David Chandler, [MIT-Designed Project Achieves Major Advance Toward Fusion Energy](#), MIT News (2021).

⁴³⁰ See [Department of Energy to Provide \\$21 Million for Artificial Intelligence and Machine Learning Research on Fusion Energy](#), U.S. Department of Energy (2020); Martin Greenwald, [Machine Learning, Harnessed to Extreme Computing, Aids Fusion Energy Development](#), MIT News (2022); Barry Fitzgerald, [Faster Fusion Reactor Calculations Thanks to Machine Learning](#), Phy.org (2021); Rebecca Sohn, [Fusion Plasmas Meet Their Match in Reinforcement Learning](#), IEEE Spectrum (2021).

and will continue to enable – faster and more efficient fusion research and development.⁴³¹ Furthermore, national advantages in materials engineering⁴³² and manufacturing⁴³³ may need to be cultivated to meet requirements of demonstration and operational facilities. Private fusion firms are sufficiently capitalized and likely will be able to achieve specific technological milestones, but government support will be key to catalyze and scale a commercial ecosystem.

Recognizing the need for national leadership, the U.S. Government recently launched a laudable *Bold Decadal Vision for Commercial Fusion Energy*.⁴³⁴ Already the vision has increased coordination within government, and efforts such as the Department of Energy’s (DOE) milestone-based development program are expanding public-private partnerships.⁴³⁵ Nonetheless, shifting fusion from a purely scientific to a commercial mission will require a deep cultural shift within the government.

Other nations have also recognized fusion’s importance, and some are better organized for the race ahead. The United Kingdom, for example, has made fusion a central tenet of its Ten Point Plan for a Green Industrial Revolution,⁴³⁶ selected the location for a national pilot plant,⁴³⁷ and attracted foreign fusion companies through a favorable regulatory environment.⁴³⁸ More troublingly, China has plans for a fusion pilot plant and is replicating U.S. companies’ technological approaches.⁴³⁹ Even if not the first to achieve a breakthrough, China’s ecosystem

⁴³¹ See UK Atomic Energy Authority, [AI Has Star Power to Accelerate Fusion](#), UK Government (2022); Jonathan Spencer Jones, [AI to Accelerate Fusion R&D](#), Power Engineering International (2022); Abigail Beall, [Why Cracking Nuclear Fusion Will Depend on Artificial Intelligence](#), NewScientist (2020); Oliver Peckham, [Eyeing Nvidia’s Omniverse for Fusion Reactor Design](#), HPCwire (2022).

⁴³² See Oliver Freeman, [Nuclear Fusion: Building a Star on Earth Is Hard, Which Is Why We Need Better Materials](#), The Conversation (2021); [UK Fusion Materials Roadmap](#), UK Atomic Energy Authority (2021); Valentina Ruiz Leotaud, [Lithium Could Help Control Extreme Heat in Future Fusion Facilities](#), Mining.com (2021).

⁴³³ See [Future Fusion Reactors Could Be Built on 3D-Printed Ceramics](#), Oak Ridge National Laboratory (2021).

⁴³⁴ [Readout of the White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy](#), The White House (2022).

⁴³⁵ [Department of Energy Announces \\$50 Million for a Milestone-Based Fusion Development Program](#), U.S. Department of Energy (2022).

⁴³⁶ A £222 million public-private partnership will build a pilot plant by 2040 and another £184 million public-private partnership will lay the foundations for commercial fusion innovation. See [Ten Point Plan for a Green Industrial Revolution](#), UK Government at 26 (2020).

⁴³⁷ The UK announced in October a power station in Nottinghamshire as the site for a prototype fusion plant it plans to build by 2040. A concept design for the plant is expected to be completed by 2024. See [Site of UK’s First Fusion Energy Plant Selected](#), UK Government (2022).

⁴³⁸ For example, a top Canadian fusion company, General Fusion, decided to build its first reactor in the UK. See Jonathan Tirone, [Bezos-Backed Fusion Startup Picks U.K. to Build First Plant](#), Bloomberg (2021).

⁴³⁹ The PRC called for "comprehensive research facilities for critical systems of fusion reactors" in its 14th Five Year Plan. See [CSET Original Translation: China’s 14th Five-Year Plan](#), Center for Security and Emerging Technology at 14 (2021). PRC efforts underway to pursue fusion include a startup called Energy Singularity that has raised an estimated \$59 million, and a government backed research effort called the Experimental Advanced Superconducting Tokamak. The ENN Fusion Technology R&D Center claims to be one of seven companies with over \$200 million in funding. See [Energy Singularity - Funding, Financials, Valuation & Investors](#), Crunchbase (last accessed 2022); [The Global Fusion Industry in 2022](#), Fusion Industry Association (last accessed 2022). Another PRC-backed initiative is the Experimental Advanced Superconducting Tokamak (EAST) reactor program. See Ben Turner, [China’s \\$1 Trillion ‘Artificial Sun’](#)

would likely be able to rapidly catch up and scale fusion technology – as it did with solar photovoltaics a decade ago.⁴⁴⁰

Action Plan Elements:

Get Fusion On the Grid by 2030:

Private sector progress has already compressed government fusion timelines by over a decade. Companies expect to achieve net energy by 2024 or 2025, are building pilot plants today that they expect to be operational as soon as 2030, and believe they can put fusion on the grid by the early 2030s.⁴⁴¹ With the right incentives, the government can accelerate those timelines. Congress has appropriated \$50 million for a DOE Milestone Program to support commercial pilot plant efforts,⁴⁴² but longer-term and higher-dollar funding will be required to instill commercial confidence and enable long-term government planning.⁴⁴³

- To incent competition among companies to achieve their pilot plant plans on an even shorter timeline, the Biden Administration should announce a “Fusion Energy Earthshot”⁴⁴⁴ of having at least three fusion pilot plants on U.S. soil successfully deliver fusion energy to the grid by 2030.
- Congress should fully appropriate the \$325 million authorized for the DOE Milestone Program.⁴⁴⁵ DOE should use companies’ milestone program applications to inform future fusion funding, starting with the FY24 budget request.

[Fusion Reactor Just Got Five Times Hotter Than the Sun](#), Live Science (2022). On China’s plans for a fusion pilot plant, See [Federal Pivot to Supporting Commercial Fusion Energy Underway](#), American Institute of Physics (2022).

⁴⁴⁰ See David Hart, [The Impact of China’s Production Surge on Innovation in the Global Solar Photovoltaics Industry](#), Information Technology & Innovation Foundation (2020).

⁴⁴¹ On commercial timelines, see Haje Jan Kamps, [Helion Secures \\$2.2B to Commercialize Fusion Energy](#), TechCrunch (2021); David Chandler, [MIT-Designed Project Achieves Major Advance Toward Fusion Energy](#), MIT News (2021). On current U.S. Government timeline, see John Mandrekas & Colleen Nehl, [Informational Webinar: Milestone-Based Fusion Development Program](#), U.S. Department of Energy at Slide 4 (2022).

⁴⁴² The first phase of the milestone program is expected to make between three and five awards, up to a total \$50 million, for “pre-conceptual designs and technology roadmaps.” Milestone applications allow for-profit companies to partner with national labs, universities, and other organizations. See [Milestone-Based Fusion Development Program Funding Opportunity Announcement](#), Department of Energy at 11 (2022).

⁴⁴³ The milestone program was modeled on the NASA COTS program, which was successful because an upfront investment of \$500 million over five years gave the private sector confidence and enabled NASA to plan over a longer-time horizon. See Written testimony of Bob Mumgaard before the Senate Committee on Energy & Natural Resources, [The Federal Government’s Role in Supporting the Commercialization of Fusion Energy](#) (2022); Dennis Stone, [NASA’s Experience in Other Transaction Authority to Foster Development](#), NASA (2022).

⁴⁴⁴ First announced in June 2021, DOE’s “Energy Earthshot” program aims to “accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade.” Previous Energy Earthshots have included the Hydrogen Shot, the Long Duration Storage Shot, the Carbon Negative Shot, the Enhanced Geothermal Shot, the Floating Offshore Wind Shot, and, most recently, the Industrial Heat Shot. See [Energy Earthshots Initiative](#), U.S. Department of Energy (last accessed 2022).

⁴⁴⁵ The Energy Act of 2020 authorized a combined \$325M for FY 2021-2025 for DOE to create a “‘milestone-based development program’ that would award participants funding to support the R&D to enable construction of new full-scale fusion systems ‘capable of demonstrating significant improvements’ in performance within 10 years of the

- A National Mission Manager (NMM) in government should be empowered and held to account for getting fusion to the grid. The NMM must have the necessary budgetary and legal authorities to effectively implement the national action plan.
- The NMM should actively encourage multiple technical pathways — including magnetic, inertial, and magneto-inertial — for fusion at this stage. Competition amongst companies on different tech paths could accelerate commercialization, reduce the cost to consumers, mitigate supply chain vulnerabilities, and ultimately enhance the United States’ competitive position.⁴⁴⁶
- The government should validate technical progress and set new fusion milestones to signal to private markets, lawmakers, regulators, suppliers, and the public the growing reality of commercial fusion.

Empower DOE with a Commercial Fusion Mission:

Fusion can no longer be an incremental science mission within DOE.⁴⁴⁷ A program office with budgetary authority and a commercial fusion mission will be necessary to move fusion from the theoretical to the practical. The time to create this office is now. Waiting until a breakthrough occurs to create such an office will yield valuable time to other countries who will seek scale and commercialize the technology first.

- Congress should create an Office of Fusion Energy at the Department of Energy to implement the *Bold Decadal Vision*. The office’s mission should be to get fusion on the grid and ultimately serve as the policy apparatus for a thriving U.S. fusion ecosystem.⁴⁴⁸ DOE’s Lead Fusion Coordinator could serve as the National Mission Manager.⁴⁴⁹

Leverage Actors’ Core Strengths:

Different actors in the fusion ecosystem bring different strengths to the table. The U.S. Government can increase the impact of the *Bold Decadal Vision* by doubling down on what is already working, while streamlining efforts that are unnecessarily duplicative. Aligning

legislation’s enactment.” See Amy Roma, [Energy Act of 2020—Variety of Provisions for Fission and Fusion](#), Hogan Lovells (2020).

⁴⁴⁶ Those who attempted to scale solar energy reflected that delaying deciding a technical path would have been beneficial, see Garrett Nilsen, [Scaling Solar: Lessons Learned](#), U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy at slide 13 (2022).

⁴⁴⁷ Fusion is currently a basic science mission within the Department of Energy’s Office of Science. See [Fusion Energy Sciences](#), U.S. Department of Energy (last accessed 2022).

⁴⁴⁸ In a private engagement with SCSP, a fusion company noted that the Department of Energy’s Office of Nuclear Energy could provide a model for an applied fusion office.

⁴⁴⁹ The Bold Decadal Vision created this position, which currently reports to the Undersecretary for Science and Innovation. See [Fact Sheet: Developing a Bold Vision for Commercial Fusion Energy](#), The White House (2022).

ecosystem efforts around actors' core strengths in the following ways would streamline progress and deliver more impactful results:

- Fusion companies should focus on achieving a fusion breakthrough and competing against one another to build the best fusion pilot plants and commercialization plans.
- DOE and the national labs should focus on developing the supporting infrastructure (such as test stands), basic R&D, and science that will enable industry.⁴⁵⁰ Additionally, they should lead the charge in supporting the education and training of the next generation of fusion energy scientists, engineers, and professionals.
- Public-private partnerships (PPPs) should be targeted to the areas of greatest potential impact. Government's scientific know-how and resources can continue to help de-risk and incentivize the frontiers of fusion research but must also increasingly help build out a commercial fusion ecosystem.

Add Government Fuel Where It Will Accelerate Commercialization:

Government spending on fusion will be essential both for catalyzing a commercial fusion ecosystem and eventually for supporting the delivery of fusion energy as a public good. The science programs underway today will remain important for driving the field forward, but Congress should make fusion activities eligible for other climate and national security-related funding vehicles today, and should prepare to grow the funding pot for longer-term fusion needs tomorrow. In the meantime, the government may find private actors interested in voluntarily supporting longer-term ecosystem needs.

- *Continue Partnerships like INFUSE & ARPA-E:*⁴⁵¹ The annually-recurring DOE INFUSE program, which gives companies access to labs and up to 80 percent government cost share,⁴⁵² should be sustained as a recurring expenditure and should focus on high-risk projects and proof-of-concepts for associated technologies that support the fusion ecosystem. Fusion-focused ARPA-E programs – which have leveraged 5-15x government dollars in private investment⁴⁵³ – should be appropriated on a recurring rather than one-time basis.

⁴⁵⁰ See Andrew Holland, [The Voice of a New Industry](#), Fusion Industry Association (2022).

⁴⁵¹ The Biden Administration requested \$32 million for all fusion-related public-private partnerships in fiscal year 2023, encompassing both the milestone-based program as well as the smaller INFUSE program, which supports collaborations between private fusion ventures and DOE national labs. See [DOE Office of Science Budget: FY22 Outcomes and FY23 Request](#), American Institute of Physics (2022).

⁴⁵² [New DOE Program Connects Fusion Companies with National Labs](#), U.S. Department of Energy (2022); Ahmed Diallo, [Innovation Network for Fusion Energy \(INFUSE\) Program Overview](#), Princeton Plasma Physics Laboratory at 5 (2021).

⁴⁵³ \$30 million government funding in ARPA-E ALPHA program leveraged \$570 million in private funds, and \$40 million government funding in BETHE leveraged \$200 million in private funding. See Written testimony of Bob

- *Include Fusion in Other Existing Programs:* Government should consider additional vehicles for funding and partnering with fusion companies, such as making fusion-related activities eligible for clean energy tax credits. If fusion meets key mid-decade milestones, these programs should be expanded to add additional funds to support a fusion-focused buildout.
- *Align Investment Now for Longer-Term Needs:* The government should start planning for and aligning funding to build the R&D facilities and infrastructure, like test stands, that will be necessary to scale commercial fusion. Government can rally voluntary private investment around these ecosystem gaps by convening investment alignment working groups. While the government should ideally lead in funding R&D facilities, private actors could get the ball rolling on long pole items like the Fusion Energy Sciences Advisory Committee (FESAC)-recommended Fusion Prototypic Neutron Source (FPNS) test facilities.⁴⁵⁴

Determine a Basic Regulatory Framework Within the Next Year:

Companies need to know the regulatory world within which they will be operating to map their fusion commercialization plans. The Nuclear Regulatory Commission (NRC) is considering three basic options for fusion regulation: a materials framework like particle accelerators, a utilization framework like fission, or a hybrid of the two.⁴⁵⁵ Adopting fission regulations for fusion – a fundamentally safer energy source – would likely drive commercial actors out of the United States.⁴⁵⁶ Prolonged regulatory uncertainty via a hybrid approach would risk the same, and could cede to rivals first mover advantage in setting global safety standards and shaping international standards bodies.

- The NRC should vote as early as possible to codify the use of a byproduct materials framework (Part 30) to regulate fusion, rather than a utilization framework (Part 53) or a hybrid approach (Part 30/Part 53).⁴⁵⁷ The details of these regulations can be worked out

Mumgaard before the Senate Committee on Energy & Natural Resources, [The Federal Government's Role in Supporting the Commercialization of Fusion Energy](#) at 7 (2022).

⁴⁵⁴ Creating a Fusion Prototypic Neutron Source facility will be an essential step towards commercializing fusion as it would generate important data for the development of the necessary high-performance structural and plasma-facing materials. See Brian Egle, et al., [U.S. Fusion D-Li Neutron Irradiation Facility: Fusion Prototypic Neutron Source \(FPNS\) Technology Study](#), Oak Ridge National Laboratory (2019)

⁴⁵⁵ James Broughel, [New NRC Report Outlines Options For Regulating Nuclear Fusion](#), Forbes (2022).

⁴⁵⁶ Fusion differs from traditional nuclear fission in that it relies on a continuous input of fuel as opposed to a chain reaction. See [Fusion – Frequently asked questions](#), International Atomic Energy Agency (last accessed 2022); Amy C. Roma & Sachin S. Desai, [The Regulation of Fusion – A Practical and Innovation-Friendly Approach](#), Hogan Lovells at 12-13 (2020).

⁴⁵⁷ [Preliminary White Paper – Licensing and Regulating Fusion Energy Systems](#), U.S. Nuclear Regulatory Commission (2022).

over a longer timeline, but a basic framework that separates fusion from fission must be determined today.

Balance Information Sharing and Intellectual Property Protection:

As with much of the science community, fusion research has been highly collaborative. The rise of private fusion companies has begun to shift those traditional information sharing paradigms. National labs have decades of R&D experience, but gaps in the discourse between the labs and private companies can cause commercial actors to waste resources reinventing the wheel. Public-private partnerships can help bridge those gaps and foster needed trust, but all ecosystem actors must recognize and guard against unlawful or unwanted knowledge transfer. Rivals are already attempting to duplicate U.S. fusion companies' successes,⁴⁵⁸ and as fusion becomes a commercial reality, sabotage and IP theft will likely grow.⁴⁵⁹

- DOE should leverage ongoing and new PPPs to enhance information sharing between the national labs and commercial fusion companies, and should explore mechanisms for streamlining contracting and IP sharing processes so that PPPs can keep pace with industry.
- The government should provide companies at the leading edge of fusion technologies with access to adequate training and resources to mitigate information security vulnerabilities such as cybersecurity risks and intellectual property theft.
- ITER, a scientific collaboration amongst 35 countries, should remain an important driver of international fusion research and information sharing.⁴⁶⁰ Looking ahead, ITER can also provide a forum for shaping the global norms of an international commercial fusion ecosystem and a model for how democracies can engage in global research and development while building in select research security measures.

Bolster the Fusion Supply Chain:

Fusion supply chains that used to exist in the United States have degraded due to long government timelines and have since moved abroad where they are vulnerable to geopolitical forces.⁴⁶¹ Already, some fusion startups have reported that they have trouble sourcing complex

⁴⁵⁸ See [Chinese Fusion Energy Programs Are A Growing Competitor in the Global Race to Fusion Power](#), Fusion Industry Association (2021); [Federal Pivot to Supporting Commercial Fusion Energy Underway](#), American Institute of Physics (2022) (citing congressional testimony by Princeton Plasma Physics Lab Director Steven Cowley).

⁴⁵⁹ Fusion companies noted in private engagements with SCSP that IP protection is one area where fusion companies that do not or cannot prioritize security costs can learn best practices from the national labs.

⁴⁶⁰ [What is ITER?](#), iter.org (last accessed 2022).

⁴⁶¹ See Daniel Clery, [Out of Gas](#), Science (2022); Catherine Clifford, [This Government Lab in Idaho Is Researching Fusion, the 'Holy Grail' of Clean Energy, as Billions Pour into the Space](#), CNBC (2022); Alan Neuhauser, [Scoop: Russia Sanctions Threaten Commonwealth's Supply Chain](#), Axios (2022); David Matthews, [ITER Faces Further Delays if Key Parts Stuck in Russia](#), Science Business (2022).

components from within the U.S. due to an absence of domestic firms capable of manufacturing them.⁴⁶²

- The NMM should lead a public-private roadmapping exercise to identify supply chain bottlenecks for the wider set of inputs required for commercialization and reshore or friendshore suppliers of key precision materials.⁴⁶³ Leveraging the commercial demand for complex industrial components to scale a durable fusion supply chain can concurrently help drive a revitalization of U.S. manufacturing.

Foster a Broad Base of Fusion Talent:

The United States must convince the 21 commercial fusion companies⁴⁶⁴ based in the U.S. to stay and attract the fusion entrepreneurs of the future. Public-private incentives and regulatory certainty will go a long way, but must deliver before the business equation pushes firms abroad.

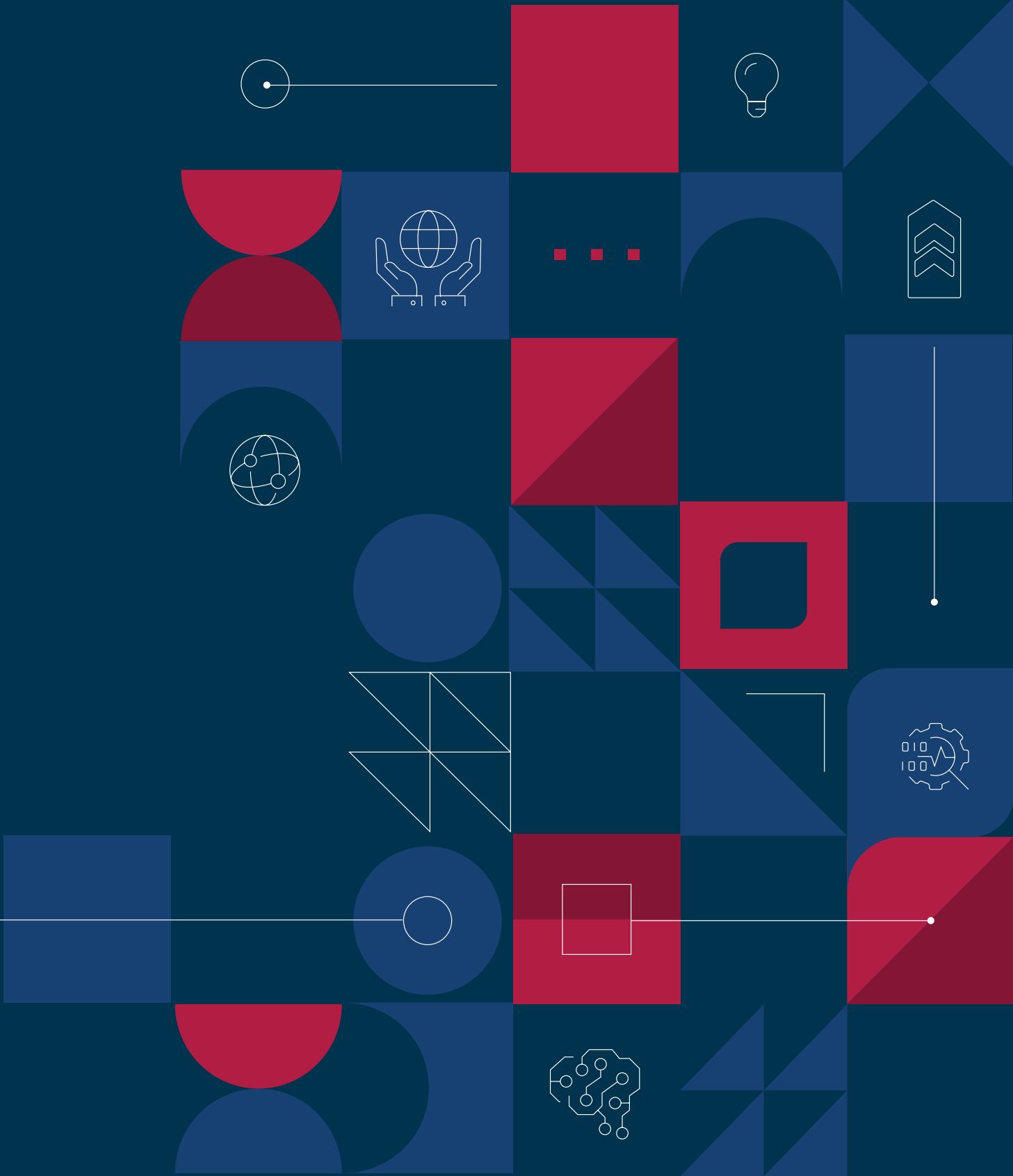
- Framing work associated with fusion as part of a bold, national mission – such as powering the nation on limitless, clean energy – can drive educational investments and inspire future generations to pursue careers to help recreate the power of the sun on earth.⁴⁶⁵
- Experts can help policymakers at all levels, including state and local officials, understand the potential of fusion energy and disseminate the benefits regarding fusion’s safety and its potential to their constituents.

⁴⁶² SCSP Engagement with a commercial fusion company (May 2022).

⁴⁶³ This could mirror the roadmapping exercise conducted by the UK’s atomic energy agency in 2021. See [UK Fusion Materials Roadmap](#), UK Atomic Energy Authority (2021).

⁴⁶⁴ [The Global Fusion Industry in 2022](#), Fusion Industry Association at 7 (2022).

⁴⁶⁵ See e.g., [Students at Institutions Across the U.S. Learn About Plasma and Fusion Research in New Program Managed by PPPL](#), Princeton Plasma Physics Laboratory (2021).



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