U.S.-ROK TECH COOPERATION

BATTERIES, BIOTECH, AND QUANTUM TECHNOLOGIES

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THE NATIONAL BUREAU *of* ASIAN RESEARCH

Edited by Jungmi Cha and Doug Strub

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Introduction: Building a U.S.-ROK Quadruple Partnership—Aligning Innovation, Industry, Supply Chains, and Policy

Jungmi Cha

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NOTE: The views expressed are those of the author and do not reflect the views of any organization with which the author is affiliated.

Studies on the cycles of great-power ascendance and decline have emphasized technological innovation as a central factor in the rise and fall of great powers.[1] Nations that pioneer and adopt these leading sectors of technological innovation secure global leadership. In the context of a shifting geopolitical landscape, great powers are increasingly recognizing that today's global order may be undergoing a transitional phase, in which societies that most effectively capitalize on technological advances will emerge on top.

In the United States, the Biden administration's 2022 National Security Strategy argued that "the world is changing" and is "at a significant inflection point in world history."[2] It emphasized that technology is central to today's geopolitical competition and to the future of national security, the economy, and democracy.[3] Similarly, the Trump administration's 2017 National Security Strategy clearly noted that "losing our innovation and technological edge would have far-reaching negative implications for American prosperity and power."[4] The People's Republic of China (PRC) has also framed the current era as a stage of this ongoing cycle of global leadership change. One of Xi Jinping's signature phrases, "great changes unseen in a century," emphasizes the concurrent transformation of global power dynamics and the role of technological innovations in driving these shifts. The 14th Five-Year Plan (2021–25) highlights that these changes are partly driven by a "new scientific and technological revolution" and aims for China to become a world-class innovative nation by 2035. The Republic of Korea (ROK) has also emphasized the importance of technology and prioritized policies to advance the country's technological leadership. The Ministry of Science and ICT highlights that global technological competition centers on critical emerging technologies and that securing "science and technology sovereignty" through advanced technologies is key to driving national growth.[5]

The perception among major powers that they are at a decisive moment in the struggle for future global leadership has been a driving force in shaping today's geopolitics of technology. With the advancement of disruptive innovations, emerging leading technologies have become pivotal battlegrounds, profoundly influencing economic, military, and geopolitical landscapes. In this context, this report focuses on batteries, biotechnology, and quantum technology as critical emerging technologies for U.S.-ROK cooperation.

Shifts in Geopolitics and World-Changing Technologies

Emerging Sectors for Global Leadership: Batteries, Biotechnology, and Quantum Technologies

The United States' 2024 "Critical Emerging Technologies List Update" defines eighteen areas, including clean energy generation and storage, biotechnology, and quantum technology,

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[1] See, for example, Paul Kennedy, *The Rise and Fall of the Great Powers: Economic Change and Military Conflict from 1500 to 2000* (New York: Random House, 1989); and George Modelski and William Thompson, *Leading Sectors and World Powers: The Coevolution of Global Economics and Politics* (Columbia: University of South Carolina Press, 1996).

[2] White House, *National Security Strategy* (Washington, D.C., October 2022), 6.

[3] Ibid., 32.

[4] White House, *National Security Strategy of the United States of America* (Washington, D.C., December 2017), 21.

[5] Ministry of Science and ICT of the Republic of Korea (ROK), "Daehanminguk Gwahakgisulju-gwon Cheongsa-jin, Je1cha Gukgajeollyakgisul Yuseong Gibon-gyehoek ('24–28) Surip" [Blueprint for the Science and Technology Sovereignty of the Republic of Korea, Establishment of the First Basic Plan for National Strategic Technology Development 2024–2028], August 26, 2024, https://www.msit.go.kr/bbs/view.do?mId=113&bbsSeqNo=94&nttSeqNo=3184844.

as critical emerging technologies.[6] Meanwhile, the PRC's 14th Five-Year Plan designates ten areas as national strategic technologies, including quantum information and biotechnology, and identifies nine strategic emerging industries, such as biotechnology and new energy. The Chinese Communist Party (CCP) has emphasized that the ongoing scientific and technological revolution, particularly in fields such as in biotechnology and quantum science, is reshaping the international order.[7] Reflecting this priority, the Political Bureau of the CCP Central Committee has held collective study sessions focused on quantum,[8] biosecurity,[9] and new energy technology and batteries.[10] Similarly, the ROK has identified twelve key national strategic technology areas, including batteries, biotechnology, and quantum technology.[11] In April 2024 the National Science and Technology Advisory Council of the ROK approved three major game-changing technology initiatives: artificial intelligence (AI) semiconductors, advanced biotechnology, and quantum technology, setting the goal of becoming one of the top three global leaders in these fields by 2030.[12]

Digital and green transitions have become key priorities of both developing and developed countries. Advances in battery technologies are playing a central role in this process. Global demand for lithium-ion batteries is expected to soar over the next decade, with the number of gigawatt hours required increasing from around 700 gigawatt hours in 2022 to 4.7 terawatt hours by 2030.[13] Biotechnology is an emerging sector with impactful applications across numerous sectors ranging from health to the green transition to defense. Based on trends of 10%–15% annual revenue growth, the world bioeconomy could exceed $20 trillion by 2030.[14] Quantum technology is likely to be the next "game changer" after AI, permeating every key sector of the economy. The market value of quantum technology could reach trillions of dollars within the next decade and create $450–$850 billion of economic value by 2040.[15] Batteries, biotechnology, and quantum technology are thus pivotal for future global economic growth.

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6 White House, "Critical and Emerging Technologies List Update," February 2024.

7 Luo Jianbo, "Cong quanju gaodu lijie he baguai shijie bainian weiyou zhi da bianju" [Understanding and Grasping the Great Changes in the World from a Global Perspective], Chinese Communist Party News Network, June 7, 2019.

8 "Xi Jinping zai Zhongyang Zhengzhiju di ershisi ci jiti xuexi shi qiangdiao shenke renshi tuijin liangzi keji fazhan zhongda yiyi qianghua liangzi keji fazhan zhanlue mouhua he xitong buju" [Xi Jinping Emphasizes during the 24th Collective Study of the Central Politburo the Profound Significance of Advancing Quantum Science and Technology Development and the Need to Strengthen Strategic Planning and Systematic Layout for Quantum Science and Technology Development], *People's Daily*, October 17, 2020, http://politics.people.com.cn/n1/2020/1017/c1024-31895752.html.

9 "Ba jiaqiang shengwu anquan jianshe bai shang gengjia tuchu de weizhi—woguo chixu tisheng guojia shengwu anquan zhili nengli" [Place Greater Emphasis on Enhancing Biosecurity Infrastructure—Our Country Continues to Strengthen National Biosecurity Management Capabilities], PRC government website, October 1, 2021, https://www.gov.cn/xinwen/2021-10/01/content_5640653.htm.

10 "Xi Jinping zai Zhonggong Zhongyang Zhengzhiju di shier ci jiti xuexi shi qiangdiao dalituimao woguo xin nengyuan gao zhiliang fazhan wei gongjian qingjie meili shijie zuochu gengda gongxian" [Xi Jinping Emphasizes at the 12th Collective Study Session of the CCP Central Politburo: Vigorously Promote High-Quality Development of China's New Energy and Make Greater Contributions to Building a Clean and Beautiful World], *People's Daily*, March 1, 2024, http://politics.people.com.cn/n1/2024/0301/c1024-40186875.html.

11 Ministry of Science and ICT (ROK), "Gisulpaegwon gyeongjaeng-eseo urinarareul jikil '12dae Gukgajeollyakgisul' gongsik hwakjeong" [Ministry of Science and ICT, "Official Confirmation of the '12 Major National Strategic Technologies" to Protect Our Country in the Technological Hegemony Competition], December 12, 2023, https://www.msit.go.kr/bbs/view.do?mId=113&bbsSeqNo=94&nttSeqNo=3183868.

12 "AI Bandoche Cheomdan Baio Quantum, 3dae Geimcheinjeo Gisul Inisyeotibeu Hwakjeong" [AI Semiconductors, Advanced Biotech, Quantum: The Confirmation of Three Major Game-Changer Technology Initiatives], Asia Gyeongje, April 25, 2024, https://view.asiae.co.kr/article/2024042517114510956.

13 McKinsey and Company, "Battery 2030: Resilient, Sustainable, and Circular," January 16, 2023, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular.

14 U.S. Director of National Intelligence, "The Future of Biotech," Global Trends, April 2021, https://www.dni.gov/files/images/globalTrends/GT2040/NIC-2021-02494--Future-of-Biotech--Unsourced--14May21.pdf.

15 Andrea Willige, "Explainer: What Is Quantum Technology and What Are Its Benefits?" World Economic Forum, July 3, 2024, https://www.weforum.org/stories/2024/07/explainer-what-is-quantum-technology; and Jean-François Bobier et al., "The Long-Term Forecast for Quantum Computing Still Looks Bright," BCG, July 18, 2024, https://www.bcg.com/publications/2024/long-term-forecast-for-quantum-computing-still-looks-bright.

Convergence of Technology and Security

If states decide to convert their economic innovations into military power, leading sectors could shape the effectiveness and speed of operations, cementing operational and tactical advantages for the innovator.[16] The advancements of batteries, biotechnology, and quantum technology are increasingly integral to national security and defense, prompting nations to re-evaluate strategies for safeguarding their technological edge. The U.S. *National Defense Science and Technology Strategy 2023* identified fourteen core emerging technology areas that are critical to national security. Among them, biotechnology and quantum technology were highlighted as top priorities in seed areas, while renewable energy was included as one of the effective adoption areas.[17] China also recognizes the applications and strategic significance of these technologies for national security and is actively applying them to its military modernization. The U.S. Department of Defense's latest report on the PRC's military and security developments emphasizes that Beijing's national strategy focuses on key civilian and military technologies, such as quantum information science and biotechnology, while investing heavily in new energy systems.[18] The ROK Ministry of National Defense has also designated ten critical defense strategic technologies as advanced technologies, including quantum and energy.[19] Many key technological tools that will shape future warfare require higher electrical energy capacity and advanced energy storage.

The development of dual-use technologies has increasingly blurred the line between civilian innovation and military applications, reflecting the growing importance of security-driven advancements. This dual functionality of critical emerging technologies in the shifting international order has intensified innovation-driven competition and heightened political scrutiny of technology exchanges among major powers, reshaping the global dynamics of technological cooperation and regulation.

The Changing Geopolitics of Technology and Great-Power Competition

Shifting global power dynamics and the convergence of security and technology have reshaped the technological landscape, contributing to the emergence of a bifurcated technological order. With the PRC's rise in critical emerging technologies and intensifying geopolitical competition, Chinese self-reliance and self-sufficiency in these sectors have strengthened, while global dependence on Chinese materials and products has continued to grow. China has consolidated control over much of the battery supply chain, from upstream mining and processing of critical minerals to midstream and downstream production of battery components and end products such as batteries for electric vehicles.[20] China's biotech sector has also been rapidly expanding, solidifying its global presence. The country's decades-long biotech investments have positioned it as a global leader,

16 Lauro Borges, "Leading Sectors and Polarity Change in the Context of U.S.-China Competition: A Process-Based Analysis of the Origins of Polarity Shift," *International Politics* 60 (2023): 1164.

17 U.S. Department of Defense, *National Defense Science and Technology Strategy 2023* (Washington, D.C., May 2023), 3, https://media.defense.gov/2023/May/09/2003218877/-1/-1/0/NDSTS-FINAL-WEB-VERSION.PDF.

18 U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China 2024* (Washington, D.C., December 2024), 24, https://media.defense.gov/2024/Dec/18/2003615520/-1/-1/0/MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA-2024.PDF.

19 Ministry of Defense (ROK), *Gwahakgisulganggun yuksungeul wihan gukbanggwahakgisulhyeoksin gibongyehoek balpyo* [Basic Plan for Defense Science and Technology Innovation to Build a Science and Technology-Oriented Strong Military Announced] (Seoul, April 2023), https://nsp.nanet.go.kr/plan/main/detail.do?nationalPlanControlNo=PLAN0000038862.

20 U.S.-China Economic and Security Review Commission, "2024 Report to the Congress," November 2024, 10, https://www.uscc.gov/sites/default/files/2024-11/2024_Annual_Report_to_Congress.pdf.

while the West was slower to prioritize biotechnology. While the United States maintains an edge in quantum computing, China has secured a clear lead in quantum communication and made massive state-led investments, dominating global quantum patents.[21] It reports over $15 billion in public funding for quantum research, significantly surpassing the United States and offsetting its private-sector shortfall with state investment.[22] China has resolved to develop an independent, de-westernized supply chain, especially for superconducting supercomputers.[23] Moreover, the high levels of investment across the battery, biotech, and quantum sectors in the PRC come primarily from Chinese investors (headquartered in China).[24]

Amid escalating great-power competition and the PRC's technological rise, the West has advanced a de-risking strategy. Facing geopolitical competition over critical emerging technologies and their dual-use functionality, the United States and China have expanded their efforts to regulate these technologies. The U.S. Department of Defense has added CATL, the world's largest battery maker, to a list of firms that it alleges work with China's military,[25] and a bipartisan group of lawmakers called for restricting the export of U.S. biotechnology to the PRC military.[26] The U.S. Department of Commerce also imposed export controls on quantum technology.[27] Responding to U.S. regulations, China has expanded political scrutiny of technologies. The PRC Ministry of Commerce announced a ban on the export of gallium, germanium, antimony, and superhard materials to the United States, citing national security and nonproliferation goals.[28] Outbound investments are also receiving increasing political scrutiny on both sides.

With intensifying geopolitical competition, the global interdependence of technologies and industries in these critical emerging sectors, which are vital for shaping the future world order, is weakening. Meanwhile, instability from wars and conflicts is disrupting global supply chains, shifting alliances, and fueling competition over critical resources and technologies. As a result, global technological networks in these areas are becoming increasingly bifurcated, reflecting a shift toward a more fragmented and polarized technological landscape and strengthening technological cooperation between like-minded countries.

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21 Zhang Weilan, "China Forms Basic Industry Chain for Quantum Computers, Breakthroughs Still Needed," *Global Times*, March 4, 2024, https://www.globaltimes.cn/page/202403/1308152.shtml; and Legu Zhang, "VOA Mandarin: Quantum Technology a Key Battleground in U.S.-China Competition," Voice of America, January 5, 2025, https://www.voanews.com/a/voa-mandarin-quantum-technology-a-key-battleground-in-us-china-competition-/7921654.html.

22 Hodan Omaar and Martin Makaryan, "How Innovative Is China in Quantum?" Information Technology and Innovation Foundation, September 9, 2024, https://itif.org/publications/2024/09/09/how-innovative-is-china-in-quantum.

23 Antonia Hmaidi and Jeroen Groenewegen-Lau, "China's Long View on Quantum Tech Has the U.S. and EU Playing Catch-Up," Mercator Institute for China Studies, December 14, 2024, https://merics.org/en/report/chinas-long-view-quantum-tech-has-us-and-eu-playing-catch.

24 Mathilde Velliet, *Funding a Rival: When the United States and Europe Invest in Chinese Tech* (Paris: Ifri, 2024), https://www.ifri.org/en/studies/funding-rival-when-united-states-and-europe-invest-chinese-tech.

25 Juliana Liu, "U.S. Adds Chinese Tech Giants to List of Companies Allegedly Working with China's Military," CNN, January 7, 2025, https://edition.cnn.com/2025/01/07/tech/tencent-catl-us-list-china-military-companies-intl-hnk/index.html.

26 "U.S. Lawmakers Ask Government to Consider Curbs on Biotech Exports to China's Military," Reuters, January 10, 2025, https://www.reuters.com/world/us/us-lawmakers-ask-government-consider-curbs-biotech-exports-chinas-military-2025-01-10.

27 "Department of Commerce Releases Export Controls on Quantum Technologies," National Quantum Initiative, September 6, 2024, https://www.quantum.gov/department-of-commerce-releases-export-controls-on-quantum-technologies.

28 Ministry of Commerce (PRC), "Shangwubu gonggao 2024 nian di 46 hao guanyu jiaqiang xiangguan liangyong wuxiang dui Meiguo chukou guanzhi de gonggao" [Ministry of Commerce Announcement No. 46 of 2024 on Strengthening Export Controls on Dual-Use Items to the United States], December 3, 2024, https://www.mofcom.gov.cn/zwgk/zcfb/art/2024/art_3d5e990b43424e60828030f58a547b60.html.

A Decisive Decade for Innovation and U.S.-ROK Technology Cooperation

With continued breakthroughs from disruptive technologies and intensifying geopolitical competition, the next ten years will be a decisive period for the future global order. The 2022 U.S. National Security Strategy emphasized that critical and emerging technologies are poised to retool economies, transform militaries, and reshape the world.[29] Xi Jinping has also described the next ten years as a "critical decade" for the PRC, emphasizing that new scientific and industrial revolutions in fields such as AI, quantum information, and biotechnology are driving revolutionary changes in global development and human productivity.[30] The next decade will be crucial for all nations striving to succeed in the technology race, as the ability to adapt and innovate will determine their future position in the global landscape.

Innovation Partnerships on Batteries, Biotechnology, and Quantum Technologies

In the evolving global order shaped by critical and emerging technologies, power dynamics are not a two-player game. Nations other than the United States and China are increasingly poised to play more significant roles. Open and collaborative innovation, combined with the will and capacity to harness international talent and innovative potential, are key factors for solidifying future global leadership. The 2022 U.S. National Security Strategy declared that the post–Cold War era is definitively over and that a competition is underway among major powers to shape what comes next.[31] It also emphasized that the United States can meet the challenges of this decisive decade only by partnering with countries and people around the world.[32]

Cooperation between the United States and the ROK will be pivotal. The U.S.-ROK partnership serves as a critical pillar of open and collaborative innovation, which is essential for the two countries to advance their mutual interests on the global stage and drive global technology leadership. The ROK stands out as a leading innovation hub and a powerhouse of advanced manufacturing. It ranks sixth overall among the 133 economies featured in the Global Innovation Index, placing fourth in innovation outputs and sixth in innovation inputs.[33] Whereas in the early 2000s it ranked among the top five in only 7 technologies, the ROK ranked in the top five in 24 technologies in 2024.[34] Moreover, it ranked sixth in global manufacturing output last year, contributing 2.7% to the worldwide total, according to data from the World Bank.[35] This solidifies its position as a global manufacturing powerhouse, reflecting the country's continuous innovation and competitiveness in key industries.

In particular, the ROK has emerged as a global leader in battery technology, biotechnology, and quantum technology, propelled by strong industry commitment and innovation-driven growth. Collaborative efforts between private companies in the United States and South Korea have been

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29 White House, *National Security Strategy*, 32.

30 Jungmi Cha, "China's Grand Strategy in Xi Jinping Era: Analysis on the Linkages between the Discourse of 'Great Changes Unseen in a Century,' Chinese Dream and BRI," *National Security and Strategies* 22, no. 2 (2022): 77–108.

31 White House, *National Security Strategy*.

32 Ibid., 37.

33 "Republic of Korea Ranking in the Global Innovation Index 2024," World Intellectual Property Organization, https://www.wipo.int/gii-ranking/en/republic-of-korea.

34 Matsumoto Rie, "Shifting Global Technology Landscape: Current Position of Japan as Indicated by the 'Critical Technology Tracker,'" Research Institute of Economy, Trade and Industry, August 24, 2024, https://www.rieti.go.jp/en/columns/a01_0766.html.

35 "Top 10 Manufacturing Countries in the World in 2024," Safeguard Global, August 28, 2024, https://www.safeguardglobal.com/resources/top-10-manufacturing-countries-in-the-world.

instrumental in advancing and expanding technological and industrial partnerships. Yet to further strengthen cooperation during this pivotal decade of technological advancement, both nations must deepen R&D collaborations and enhance policy coordination, supported by active engagement from their governments and research institutions. Although various cooperation frameworks, such as the Next Generation Critical and Emerging Technologies Dialogue, have been established, there is a need for more in-depth and concrete discussions within a comprehensive strategy for innovation cooperation. This strategy should encompass multiple dimensions, including technological innovation, industrial collaboration, supply chain resilience, and policy alignment, to foster more substantive and effective partnerships.

Organization of the Report: Toward a Quadruple Partnership

Amid the advancement of disruptive technologies that are crucial to future economic growth and security, as well as intensifying global strategic competition, this report aims to foster mutual engagement between the United States and the ROK by examining their respective strategies, policies, and opportunities for increased collaboration in the pivotal areas of battery technology, biotechnology, and quantum technology. By identifying the opportunities and potential benefits arising from deeper and broader U.S.-ROK collaboration, the report underscores the strategic imperative of enhanced bilateral cooperation and presents a comprehensive framework for advancing shared national interests. With contributions from leading U.S. and ROK experts, it outlines clear strategic pathways and practical initiatives aimed at driving technological breakthroughs, fostering successive waves of industrialization, and maintaining a competitive technological edge and leadership on the global stage in these three areas.

In the first chapter, Charlie Vest explains U.S. de-risking strategies in the battery supply chain and analyzes the impact of these policies on U.S.-ROK collaboration. Sangmin Shim then outlines South Korea's development policies and supply chain strategies for battery technology and examines the potential for bilateral cooperation. In the chapter's jointly authored conclusion, Shim and Vest suggest ways to strengthen cooperation by focusing on next-generation technologies, supply chain resilience, regulatory alignment, workforce development, and knowledge exchange.

In the second chapter, Hyun-Chul Kim discusses South Korea's technological and industrial strengths in biotechnology, its strategic role in the global biotech ecosystem, and its overall bio-diplomacy strategies, emphasizing the potential benefits of U.S.-ROK collaboration. Michelle Rozo then highlights the importance of biotechnology and examines gaps in U.S. policies, emphasizing the need for U.S. and allied leadership in shaping the future. In the jointly authored conclusion, Kim and Rozo propose strengthening cooperation in areas such as AI and bio-data sharing, regulatory alignment, market and innovation partnerships, biomanufacturing supply chains, and global health initiatives.

In the final chapter, Jae Young Kwon discusses South Korea's quantum technology policies and its growing quantum ecosystem. Hodan Omaar then outlines the overarching approach to quantum innovation, U.S. quantum policies, and the importance of international cooperation. In the jointly authored conclusion, Kwon and Omaar suggest policy measures to enhance U.S.-ROK cooperation, including through forming government-level science and technology partnerships, funding joint R&D programs, strengthening quantum supply chains, aligning international standards, coordinating export controls, and engaging in multilateral decision-making bodies.

This report highlights the next decade as a pivotal period for disruptive technological innovations reshaping the global order. With intensifying competition and geopolitical instability, both the United States and South Korea will face opportunities and challenges. U.S.-ROK cooperation is expected to play a pivotal role in advancing technological innovation, fostering economic growth, enhancing security, and strengthening global leadership. To this end, the report emphasizes the need for both nations to improve collaboration through a "quadruple partnership" among industries, research institutions, universities, and governments. Such a partnership would advance technological innovation through the enhancement of R&D initiatives, promotion of industrial development by fostering manufacturing cooperation and expanding international market access, reinforcement of supply chain resilience, and coordination of policies, including export controls and international standards.

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U.S.-ROK Cooperation in the Battery Sector

Charlie Vest and Sangmin Shim

EXECUTIVE SUMMARY

This chapter examines the strategic approaches of the U.S. and the Republic of Korea (ROK) to the battery sector and assesses that U.S.-ROK battery cooperation is an essential component in achieving broader decarbonization and supply chain de-risking objectives.

MAIN ARGUMENT

In the first section, Charlie Vest examines how U.S. trade and investment policies aimed at reducing supply chain dependence on China are shaping the market for Korean battery makers. Korean battery companies are the largest investors in the U.S. supply chain for electric vehicle (EV) batteries, with Chinese players increasingly locked out of the U.S. However, upstream dependence on China for critical raw materials remains high, and these dependencies are now at the center of China's retaliatory response to U.S. technology controls. In the second section, Sangmin Shim examines the global battery industry's rapid growth, driven by EV expansion and decarbonization goals, which highlights the strategic importance of U.S.-ROK collaboration. South Korea, a global leader in lithium-ion batteries, leverages R&D in solid-state and ecofriendly technologies, recycling, and supply chain diversification. The U.S., with its robust EV market and policy incentives, offers Korean companies opportunities to establish localized production, integrate supply chains, and access critical raw materials. Collaborative efforts include partnerships with automakers, research institutions, and recycling firms, advancing innovation and sustainability.

POLICY IMPLICATIONS

- Collaborative R&D initiatives between the U.S. and South Korea can accelerate breakthroughs in emerging battery technologies, such as solid-state and lithium-sulfur batteries. Establishing joint innovation hubs and government-funded projects with shared intellectual property rights would not only enhance technological advancements but also strengthen bilateral ties.
- Enhancing supply chain security through joint investments in critical mineral sourcing and advanced recycling facilities is essential. Bilateral agreements for shared material processing and stockpiling, coupled with expanded North American recycling initiatives, can reduce reliance on volatile global supply chains.
- By setting unified international standards for battery safety, performance, and recycling, the U.S. and South Korea can lead the global battery industry. Mutual recognition of certifications and co-developed regulatory frameworks for next-generation technologies will simplify market access and streamline innovation.
- The Inflation Reduction Act provides a strong foundation for promoting EV manufacturing in the U.S., while addressing national security risks posed by suppliers from countries of concern. Repealing or weakening this legislation would reduce U.S. leverage in attracting foreign investment in battery manufacturing from allied countries.

Cooperation between the United States and the Republic of Korea (ROK) on the development and production of electric vehicle (EV) batteries has been a strong point in the two countries' broader technology relations in recent years. With South Korean companies emerging as global leaders in this sector and making significant investments in U.S. production facilities, continued collaboration in this field serves both countries' technology goals and broader strategic ambitions.

In this chapter, Charlie Vest first examines U.S. policies around domestic battery development and assesses the impact of efforts to de-risk battery supply chains from China on foreign partners such as South Korea. Sangmin Shim then provides an overview of South Korea's battery development ecosystem and related policies and development strategies. The chapter concludes with a joint assessment of the policy options for the United States and South Korea to more effectively work together to achieve shared objectives.

Implications of U.S. De-risking Policy for U.S.-ROK Cooperation on Batteries[1]

Charlie Vest

Recent U.S. policy toward the manufacturing of electric vehicles and EV batteries has aimed to accelerate the adoption of EVs to meet decarbonization goals, encourage the manufacturing of critical components in North America and by U.S. allies, and reduce supply chain exposure to China and Chinese firms. The Trump administration might reduce the U.S. government's focus on decarbonization, but the electrification of transportation will continue, and intensifying U.S.-China tensions will make questions around dependence on China in the battery supply chains even more acute. As the largest investors in battery manufacturing in the United States, South Korean companies are central to U.S. goals for diversifying battery supply chains. At the same time, U.S. sourcing requirements are reshaping the way that Korean battery companies do business.

This section begins with an assessment of how U.S. trade and investment policies are shaping the market for Korean battery companies, and then evaluates data and trends in Korean battery investment in the United States. In short, U.S. policies are creating a protected market for U.S. and U.S.-allied battery companies, primarily to the benefit of U.S., Japanese, and Korean firms. However, these policies also limit how these firms can partner with upstream Chinese suppliers of critical battery materials, which maintain a dominant position in critical mineral refining.

Key Trade and Investment-Related Tools

U.S. policymakers are shaping the market with several key tools. Put together, these rules are creating a protected U.S. market for non-Chinese battery makers. However, policymakers are also aware that dependence on China in EV battery supply chains is deep, and they have crafted exceptions and carveouts to allow for more gradual de-risking. Some key actions the U.S. government has taken include the following.

Section 301 tariffs. In March 2024 the U.S. Trade Representative (USTR) announced increased tariffs on imports from China under Section 301 of the U.S. Trade Act of 1974 as part of its four-year

[1] This section is authored by **Charlie Vest**, who is an associate director at Rhodium Group and a nonresident fellow at the National Bureau of Asian Research.

review process, raising the tariffs on EVs and EV parts from China. Tariffs were increased for EVs (from 25% to 100%) and EV batteries (from 7.5% to 25%), as well as graphite, permanent magnets, and some EV-relevant critical minerals like cobalt and nickel (from 0% to 25%). Notably, the USTR did not increase tariffs on other potential EV-related products where U.S. dependence is high, such as lithium-ion battery parts or processed lithium oxide. Since the tariffs went into effect in September 2024, the decision to carve out certain battery parts likely reflected an awareness of the costs of de-risking from China in these products too quickly.

The USTR opened a separate investigation in December 2024 into China's acts, policies, and practices related to targeting of the semiconductor industry. The focus of the investigation is on mature-node chips, based on the concern that China's investments in its semiconductor industry have led to systemic overcapacity that could drive non-Chinese players out of the market. While mature-node semiconductors are in nearly every device, they are especially important to the automotive industry. A potential outcome of this ongoing investigation is tariffs or other restrictions on auto parts containing Chinese mature-node semiconductors, in an effort to further drive apart U.S.-based automakers from Chinese supply chains.

Eligibility for the Inflation Reduction Act (IRA). The Section 30D Clean Vehicle Credit in the IRA offers up to $7,500 in subsidies for vehicles that meet certain sourcing requirements around battery components and critical minerals. Vehicles are eligible for $3,750 if 60% of the value of the battery components is manufactured or assembled in North America, with the share gradually rising to 100% in 2029. An additional $3,750 is available for vehicles with batteries containing 50% critical minerals sourced from the United States or any country with which the United States has a free trade agreement in effect (which includes South Korea), with the share rising to 80% by 2027. Vehicles that contain battery content or critical minerals from foreign entities of concern (FEOCs) are disqualified from receiving the credits. Restrictions on battery components from FEOCs took effect in January 2024, while eligibility restrictions on critical minerals from FEOCs went into effect in January 2025.

The FEOC label applies to entities domiciled in China or that are owned or controlled by the Chinese government. However, the definition excludes the U.S.-based subsidiaries of privately owned (as opposed to state-owned) Chinese companies.[2] This is a critical distinction for Chinese battery companies like Envision AESC and Gotion, which are building battery plants in the United States with the goal of supplying IRA-eligible vehicles. The FEOC requirement also does not apply in the case of leased vehicles. The Section 45W Commercial Clean Vehicle Credit offers a $7,500 credit for clean vehicles that are leased to consumers rather than sold, and it does not include restrictions for content from FEOCs. The loophole has come under criticism for undermining the policy intent of de-risking U.S. supply chains from China.[3] This debate highlights the trade-off between accelerating EV adoption and de-risking supply chains. If U.S. leadership decides to prioritize de-risking, or if alternative supply chains come online faster than

[2] According to the U.S. government, "when an entity is a FEOC due to it being 'subject to the jurisdiction' of a covered nation, subsidiaries of the FEOC are not automatically considered to also be FEOCs solely based on their parent being a covered nation jurisdictional entity." See U.S. Department of Energy, "Interpretation of Foreign Entity of Concern," Federal Register, December 4, 2023, https://www.govinfo.gov/content/pkg/FR-2023-12-04/pdf/2023-26479.pdf.

[3] "Manchin Calls on Treasury Secretary Yellen to Ensure Inflation Reduction Act Vehicle Tax Credits Strengthen Domestic Manufacturing and Economic Security," U.S. Senate Committee on Energy and Natural Resources, December 13, 2022, https://www.energy.senate.gov/2022/12/manchin%20calls%20on%20treasury%20secretary%20yellen%20to%20ensure%20inflation%20reduction%20act%20vehicle%20tax%20credits%20strengthen%20domestic%20manufacturing%20and%20economic%20security.

anticipated, the White House or Congress could tighten these rules to force faster decoupling from Chinese EV supply chains.

Information and communications technology and services (ICTS) connected vehicles rule. While high U.S. tariffs have effectively blocked Chinese car exports from the U.S. market, policymakers have taken additional steps to close off the U.S. market from Chinese automakers investing in the United States or exporting from third countries. In September 2024 the Department of Commerce issued a notice of proposed rulemaking prohibiting the import or sale of connected vehicles containing certain hardware or software with a nexus to China or Russia. For now, the rule is focused on vehicle-connected systems (systems that enable external connectivity to the vehicle) and highly automated driving systems (e.g., self-driving cars). Given the trend of increased connectivity and automation in vehicles, the rule puts up high barriers to Chinese companies in the U.S. market. The rule also sends a signal to equipment manufacturers and suppliers to diversify away from the Chinese market for components. The rules are written such that software developed in China would be banned in the United States.

An earlier version of the rule included battery management systems, but the scope was narrowed in the September 2024 notice—likely out of recognition that restrictions on batteries would be too disruptive in the near term. While battery management systems are not currently covered, the rules are likely to expand after supply chains have had time to adapt. An expansion of these rules to cover battery systems would have profound impacts on Korean companies with research and development operations in China, or even those just employing Chinese nationals. The rule prohibits certain transactions with "persons owned by, controlled by, or subject to the jurisdiction or direction of the PRC," including "any person, wherever located, who is a citizen or resident of a foreign adversary."[4]

Export controls. The United States requires licenses for the export of certain batteries and battery know-how via the U.S. Commerce Control List. Since 2016, the United States and partner countries have instituted controls on battery cells with an energy density of 350 watt-hours per kilogram, a threshold unchanged since 2016. While commercialized EV batteries have not yet reached this level—Tesla's 4680-type cell has an estimated energy density of 272–296 watt-hours per kilogram—U.S. export controls require licenses for next-generation batteries being researched outside of university settings. While universities have a "fundamental research exclusion" that allows Chinese and other foreign nationals in the United States to research and publish on controlled technology in an academic setting, working on these same technologies in a proprietary setting requires export licenses that are difficult for Chinese researchers to get. These controls effectively preclude research partnerships with Chinese firms like CATL, while Korean companies can establish partnerships with American universities, such as between LG Energy Solution and UC San Diego, which have resulted in significant advancements.[5]

Inbound investment review. The Committee on Foreign Investment in the United States (CFIUS) reviews foreign investment for national security risks. Foreign businesses making acquisitions in critical technologies where export licenses are required (which includes high-performance batteries) are required to notify CFIUS before completion. The White House also issued an executive order providing additional direction to CFIUS to consider the impact of transactions

4 U.S. Department of Commerce, "Securing the Information and Communications Technology and Services Supply Chain: Connected Vehicles," Federal Register, September 26, 2024, https://www.govinfo.gov/content/pkg/FR-2024-09-26/pdf/2024-21903.pdf.

5 "A New Solid-State Battery Surprises the Researchers Who Created It," UC San Diego, September 23, 2021, https://jacobsschool.ucsd.edu/news/release/3335?id=3335.

on the resilience of critical U.S. supply chains, technological leadership, cybersecurity risks, and sensitive data. This results in a highly scrutinized investment environment for Chinese battery companies making acquisitions in the United States.

CFIUS does not generally have jurisdiction over greenfield investments, except in cases where proposed investments are adjacent to U.S. military bases. However, members of Congress have argued to include land acquisitions for certain greenfield investments, including Chinese battery plant investments, under statutory rules that require CFIUS to review investments that afford a foreign person "the management, operation, manufacture, or supply of critical infrastructure."[6] A more expansive interpretation of these rules under a new administration could potentially restrict future Chinese greenfield investments on this basis.

Given the restrictions put on Chinese EV imports and U.S.-based manufacturing, a key question is whether investment in U.S.-based battery capacity will be sufficient to meet domestic demand. Rhodium Group's analysis of the U.S. battery investment pipeline suggests that current and announced investments would supply at least 1,060 gigawatt-hours of batteries annually by 2030, above the upper bound of the projected 950 gigawatt-hours of demand.[7] These announced projects are not a certainty, particularly after the election of Donald Trump, who has vowed to repeal the IRA, and Republican control of both houses of Congress. Yet a small group of House Republicans supports retaining some IRA credits, given the economic benefits to U.S. manufacturing. There remains a pathway to U.S. battery manufacturing self-sufficiency, driven in large part by investments from Korean firms.

De-risking from Chinese critical minerals supply chains will be harder. China accounts for around 61% of lithium refining and 72% of refined cobalt.[8] This will make it hard for manufacturers to meet the IRA's credit eligibility requirement of containing no content from China. It also exposes the United States to Chinese retaliatory moves, as China ramps up tools to respond to U.S. trade and technology controls. China's advantages in EV supply chains are already in the retaliatory spotlight. In December 2024, Beijing announced export restrictions on graphite—a critical component in battery anodes—in response to new U.S. semiconductor export controls. In January 2025, it announced a draft measure to impose export controls on lithium extraction and lithium-ion battery cathode technology to prevent Chinese companies from sharing know-how with U.S. companies through joint ventures or licensing agreements.

Taking Stock

According to data collected by Rhodium Group, South Korea is the largest foreign investor in U.S. battery manufacturing.[9] For projects announced from 2018 through 2023, Korean-invested firms and joint ventures that are either operating or under construction accounted for $46 billion, or 41% of total investment in U.S. battery manufacturing (see **Figure 1**). Most of these investments are joint ventures between Korean battery makers and original equipment manufacturers, such as

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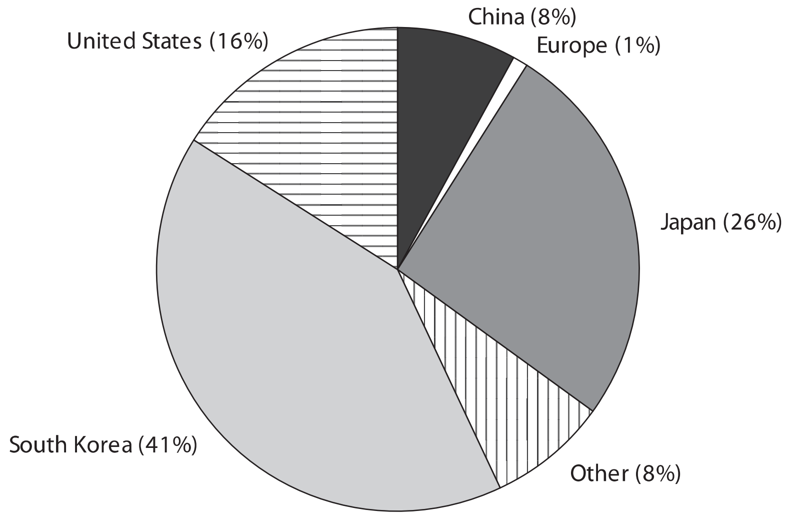
6 "Moolenaar, Rubio Demand CFIUS Review of Gotion Ownership," Office of John Moolenaar, Press Release, September 21, 2023, https://moolenaar.house.gov/media-center/press-releases/moolenaar-rubio-demand-cfius-review-gotion-ownership.

7 Rhodium Group, "Clean Investment Monitor: Assessing the EV Manufacturing Pipeline in the United States," May 30, 2024, https://rhg.com/research/clean-investment-ev-manufacturing.

8 U.S. Department of Energy, "Grid Energy Storage: Supply Chain Deep Dive Assessment," February 24, 2022, https://www.energy.gov/sites/default/files/2022-02/Energy%20Storage%20Supply%20Chain%20Report%20-%20final.pdf.

9 This includes manufacturing of electrode active materials, battery cells, and battery modules. The value of U.S.-ROK joint ventures is assigned fully to South Korea. Rhodium Group, "Clean Investment Monitor," https://www.cleaninvestmentmonitor.org.

FIGURE 1 Investment in U.S. battery manufacturing for facilities operating and under construction (2018–23)



SOURCE: Rhodium Group and the Massachusetts Institute of Technology Center for Energy and Environmental Policy Research (MIT CEEPR), Clean Investment Monitor, 2024.

NOTE: The "other" category includes both investments from other countries/regions and those investments not labeled in the data set. "United States" includes only exclusively U.S.-owned firms. Joint ventures between U.S. and foreign partners are assigned to the country of the foreign joint-venture partner.

LG Energy Solution and General Motors (Ultium Cells LLC), SK On and Ford (BlueOval SK), and Samsung SDI and Stellantis (StarPlus Energy).

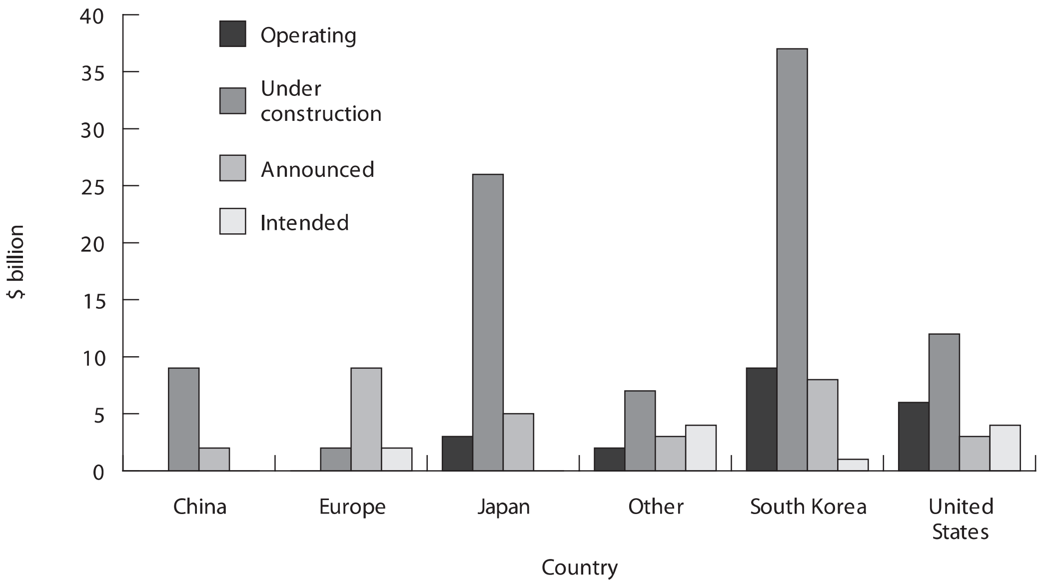
Korean companies lead in the pipeline of new construction, with around $37 billion in projects underway, followed by $27 billion for Japan, and $12 billion by U.S. companies (see **Figure 2**). According to a Korea Institute for Industrial Economics and Trade report, this has resulted in increased U.S. market share for Korean battery makers, growing from 36.2% in 2022 to 42.4% in 2023.[10]

China's investment in U.S. battery manufacturing has been limited so far given the challenging geopolitical environment. Currently, the only Chinese-owned battery-manufacturing facility in operation is Envision AESC's plant in Smyrna, Tennessee. According to Rhodium data, Chinese companies have plants, joint ventures, and partnerships, with capital expenditure totaling $11 billion, including two Envision plants under construction in South Carolina and Kentucky and two projects by Gotion. Several firms are working with Chinese companies to license their technology and manufacture the batteries themselves. Ford is building a $3.5 billion plant using technology and services from CATL, and TDK is reportedly planning to license CATL technology for a battery plant to supply GM.[11]

10 Korea Institute for Industrial Economics and Trade, "Analysis of Risks in Korea's Battery Industry Following the U.S. Presidential Election," May 2024, https://www.kiet.re.kr/common/file/userDownload?atch_no=1JW2Y2XwDoH9dVVwHDhQLQ%3D%3D.

11 "GM Looks to Japan's TDK to Make U.S. Batteries with China," Bloomberg, September 12, 2024, https://www.bloomberg.com/news/articles/2024-09-12/gm-in-talks-to-buy-chinese-batteries-made-in-us-by-japan-s-tdk.

FIGURE 2 Investment in U.S. battery manufacturing by project status



SOURCE: Rhodium Group and MIT CEEPR, Clean Investment Monitor, 2024.

NOTE: The figure includes projects announced between 2018 and 2023.

The U.S. policy debate around these investments centers on whether Chinese battery investment in the United States is facilitating de-risking by moving manufacturing and know-how to the United States, or whether this investment deepens U.S. dependence on Chinese firms. At the same time, Chinese policymakers are concerned about technology transfer to U.S. firms. Beijing reportedly scrutinized the Ford-CATL licensing deal to prevent the transfer of core technology to the United States.[12] In December 2023, it also updated its export controls on rare earth–processing technology to include neodymium magnets, which are used in electric motors. Chinese battery companies face pressure from both the U.S. and Chinese governments in ways that will make operating in the United States a significant challenge, which works to the advantage of Japanese and Korean players.

Conclusion

U.S. policy has aimed to gradually decrease dependence on Chinese EV battery supply chains, working to the advantage of Korean and Japanese companies. However, this bargain requires making substantial investment in the United States or North America and carving away dependencies on upstream Chinese supply chains and technology.

So far, U.S. de-risking toward Chinese battery supply chains has been partial. In each of the major EV investments, compromises were made to account for the fact that China remains a major player in EV battery technology and supply chains. Some Chinese battery makers have

[12] "China to Scrutinize Ford-CATL EV Battery Deal to Ensure Core Technology Isn't Shared," Bloomberg, February 16, 2023, https://www.bloomberg.com/news/articles/2023-02-16/china-to-scrutinize-ford-f-us-catl-battery-deal-to-ensure-key-tech-not-shared.

continued to invest in the U.S. market in the hopes that neither the U.S. nor Chinese government will prohibit them from doing so, despite high geopolitical tensions.

U.S. openness to Chinese battery investment in the United States depends in large part on the extent to which Korean and Japanese players can provide a competitive alternative. If it looks like U.S., Japanese, and Korean players are investing enough to meet U.S. demands in terms of battery volume and technological sophistication, U.S. policymakers are likely to take further incremental steps to shut out Chinese players. Meaningful de-risking from China would also require enormous investment in the extraction and processing of critical raw materials that has so far been slow to manifest. Furthermore, it would require collaboration among countries producing critical raw materials, such as Chile and Indonesia, that so far have looked to investment from China to scale up resource extraction and processing.

This raises questions about the evolution of global supply chains for EV batteries. U.S. efforts to create supply chains that are independent of China could create two separate ecosystems of battery supply chains, one with less dependence on China for the U.S. market and another with Chinese content for the rest of the world. This is part of a broader U.S. push to create protected trading blocs that exclude China with partners in critical products and technologies.

Thus far, EU policy has encouraged Chinese EV battery investment as part of efforts to build up local manufacturing supply chains. However, there are also concerns that opening the doors to Chinese EV battery investment could distort the single market and hurt efforts to foster European battery champions. The bankruptcy of Swedish battery maker Northvolt was a blow to this ambition and might bolster the prevailing argument that Europe needs to be open to Chinese players. Concerns about dependence on China have been highlighted in recent retaliatory moves by Beijing to control exports of critical raw materials and EV-related technologies to the United States.

If President Trump follows through on threats to impose across-the-board tariffs on partners and downsize the U.S. EV market by pressing Congress to repeal the IRA, fostering an EV trading bloc that excludes China will become harder. A more strategic approach would impose targeted tariffs on select Chinese industries, such as EVs and battery components, where the United States wants most to pare away dependence. Such tariffs could be coupled with substantial domestic and foreign investment in alternative supply chains and technology partnerships.

Enhancing U.S.-ROK Cooperation on Batteries: Opportunities, Strengths, and Pathways Forward[13]

Sangmin Shim

The global battery industry has witnessed spectacular growth in recent years, mostly thanks to the increase in production and sale of electric vehicles in many parts of the world. With the pressing need to expedite the shift toward a decarbonized transportation sector, the critical role of battery technology cannot be overemphasized.

In this context, it is both desirable and critical for the United States and South Korea to enhance cooperation in battery technology and industries, as technological advancements and industrial collaborations in this field could help these two nations successfully establish a strong footing in the sustained growth of the EV sector while securing battery supply chains free from interruptions from key competitors such as China. Before exploring the scope of further bilateral cooperation on batteries, however, it is necessary to take stock of the achievements already made by the United States and South Korea on battery cooperation and examine how each nation can supplement the other in terms of building a strong and mutually beneficial battery technology landscape.

South Korea's Policies and Development Strategy for Battery Technology

Battery technology is designated as one of the twelve "national strategic technologies" that South Korea is keen to develop through tax incentives and other financial support available under the Special Act on the Fostering of National Strategic Technology, along with other promotional measures. The following are the main features of such a development strategy.

Support for R&D and innovation. The ROK government has allocated substantial funding for battery technology R&D, as it aims to reach carbon neutrality by 2050. This funding supports research on next-generation battery technologies such as solid-state batteries, lithium-sulfur batteries, and other alternatives to lithium-ion batteries. The focus on next-generation battery development comes from the recognition that current lithium-ion technology has numerous shortcomings, especially concerning energy density and safety.

Public-private partnerships are being established to fund these initiatives, which are seen as essential to maintaining South Korea's competitive edge as the global battery market evolves. National research institutes, such as the Korea Institute of Science and Technology (KIST), also play a key role, and many have partnered with private firms to develop new battery chemistries and recycling technologies. These institutes work in collaboration with universities and tech incubators to accelerate innovation across the battery industry. Furthermore, the ROK government has supported investment in battery-recycling technology to help address global environmental concerns. This initiative not only seeks to improve sustainability but also mitigates supply chain vulnerabilities by recovering and reusing scarce materials like cobalt, nickel, and lithium from used batteries.

Battery supply chain strategy. South Korea, with limited domestic natural resources, relies heavily on raw material imports for battery production. To reduce vulnerabilities, including those arising from China's dominant role in battery supply chains, it has actively diversified these supply chains to decrease dependence on China and secure stable supplies of critical materials.

[13] This section is authored by **Sangmin Shim**, who is a professor in the Graduate School of Green Growth and Sustainability at the Korea Advanced Institute of Science and Technology (KAIST).

A majority of governmental measures to promote supply chain diversification are designed and employed on the basis of the Framework Act on Supply Chain Stabilization Support for Economic Security, which is key to providing resilience for the main industries exposed to risks from supply chain disruptions. The ROK government designated three hundred “economic security items” that are eligible to receive governmental support, including many battery components and constituent materials such as critical raw minerals.

Korean battery makers have formed partnerships and long-term contracts with mining companies in countries rich in lithium, cobalt, and nickel. For instance, they have partnered with Southeast Asian countries such as Indonesia for lithium and nickel and are investing in domestic R&D for alternative chemical processes that use fewer rare earth metals, further reducing reliance on Chinese supplies.[14] Additionally, to ensure proximity to key markets and compliance with local regulations, Korean battery companies are also establishing production facilities abroad, particularly in North America and Europe. This strategy enables them to avoid tariffs, benefit from local incentives, and enhance supply chain resilience.

To supplement these supply chain adjustments, South Korea is increasingly working to develop its processing and recycling capabilities within its borders to reduce dependency on imported processed materials. For example, SK Innovation has developed recycling technologies that enable the recovery of key materials from used batteries.[15] Through these advancements, South Korea is pushing for a circular supply chain model that supports both production and recycling within a closed-loop system.

Key players and investments. South Korea is home to several key global battery companies, and these firms—supported by government subsidies and incentives—are collectively investing billions to increase production capacity and advance R&D. As one of the largest battery manufacturers in the world, LG Energy Solution is a key player in the EV battery market, supplying companies like General Motors, Tesla, and Ford. Its investments span the globe, including large-scale production facilities in North America. LG is heavily invested in developing high-capacity and high-efficiency battery technologies. Its partnership with GM—the Ultium Cells joint venture—is a cornerstone of LG’s strategy to expand in the United States and tap into growing EV demand.[16]

Meanwhile, Samsung SDI is particularly focused on solid-state battery development, which promises enhanced safety and energy density.[17] It has established a dedicated R&D team to advance solid-state technology, aiming for commercial applications within the next decade. Samsung SDI has also made significant investments in expanding its manufacturing capabilities, including new plants in the United States and Europe, which allow it to supply automakers and technology companies more effectively.

SK Innovation complements these efforts with a strong emphasis on ecofriendly technology. It has invested in developing proprietary recycling technologies to recover cobalt, nickel, and lithium. SK Innovation is also actively involved in overseas partnerships to access raw materials sustainably. In addition, SK’s joint venture with Ford (BlueOval SK) is a major initiative to build

14 “2nd ASEAN Battery Technology Conference Announces New Collaborations and Expansion to Strengthen Southeast Asia Battery Ecosystem,” ACN Newswire, August 23, 2024, https://en.acnnewswire.com/press-release/english/92353/2nd-asean-battery-technology-conference-announces-new-collaborations-and-expansion-to-strengthen-southeast-asia-battery-ecosystem.

15 “SK Innovation Showcases Battery and Plastics Recycling Technologies at CES,” MPR Korea Certification, January 26, 2023, https://www.korea-certification.com/en/sk-innovation-showcases-battery-and-plastics-recycling-technologies-at-ces.

16 “Ultium Cells,” U.S. Department of Energy, https://www.energy.gov/lpo/ultium-cells.

17 Jasmine Choi, “Samsung SDI Establishes All Solid Battery Business Advancement Team,” *BusinessKorea*, December 8, 2023, https://www.businesskorea.co.kr/news/articleView.html.

battery-manufacturing facilities in the United States, specifically in Kentucky and Tennessee, to serve the North American EV market.[18]

Potential for U.S.-ROK Cooperation on Batteries

South Korea's strengths and weaknesses. Owing to its efforts to develop battery production and technology, South Korea possesses many strengths in these areas. Korean companies, as global leaders in battery technology, have developed significant technological expertise, particularly in lithium-ion batteries. With decades of experience and continuous investment in R&D, companies like LG Energy Solution, Samsung SDI, and SK Innovation have developed advanced battery chemistries, production methods, and recycling technologies. This expertise makes South Korea a highly attractive partner for technology transfer and joint ventures.

Korean firms have also developed advanced and efficient manufacturing capabilities, with state-of-the-art production processes that ensure high-quality batteries at scale. This manufacturing strength has enabled South Korea to capture a significant share of the global battery market. Korean battery makers have a large international footprint through partnerships with top automakers, including GM, Ford, Volkswagen, and Hyundai, allowing them to rapidly scale their operations and meet demand from various global markets. South Korea's heavy investment in solid-state and ecofriendly battery technologies is creating a pathway to alternative solutions that address issues like energy density, safety, and environmental impact and could redefine the industry.

However, the country's battery industry also faces a number of challenges, most notably its heavy dependence on imports for essential raw materials like lithium, cobalt, and nickel. This makes Korean companies vulnerable to fluctuations in global commodity prices and supply chain disruptions, as well as geopolitical tensions that could limit access to key resources. In particular, South Korea's reliance on global suppliers for processed materials and components exposes it to risks of supply chain disruptions, which have become more evident amid recent trade conflicts and the Covid-19 pandemic. South Korea's manufacturing costs can also be higher than other battery-producing nations, partly due to labor costs and energy expenses. This is prompting Korean firms to establish production plants in other regions, particularly North America and Europe, to manage costs more effectively. Lastly, South Korea faces significant competition from China's battery industry. Chinese companies have advantages in terms of access to raw materials, government support, and manufacturing costs, which places pressure on Korean firms to innovate and find more strategic markets and partnerships.

Impact of U.S. strengths and weaknesses on South Korea's battery sector. Like South Korea, the United States has its own strengths and weaknesses in the field of battery production and technology, many of which make it a suitable partner for cooperation. First and foremost, the United States has one of the largest and fastest-growing EV markets in the world. American automakers, including Tesla, GM, and Ford, are increasing their EV production rapidly. This creates a substantial and stable demand for high-quality battery supplies, which Korean companies are well-positioned to meet. In recent years, U.S. production has been boosted through supportive policies. The Inflation Reduction Act, for example, introduces significant tax credits and subsidies for batteries manufactured domestically. These policies encourage Korean battery firms to build production facilities in the United States and help secure a reliable market within the country.

[18] "SK On Establishes Joint Venture with Ford Motor Company to Manufacture Electric Vehicle Batteries," SK, November 2021, https://eng.sk.com/history/sk-innovation-establishes-joint-venture-with-ford-motor-company-to-manufacture-electric-vehicle-batteries.

The United States also has substantial reserves of critical minerals needed for battery production, such as lithium and other rare earth elements. Collaboration with U.S. suppliers provides Korean companies with a more stable and diversified supply of raw materials, reducing dependence on countries like China. In addition, the United States boasts a skilled workforce and is home to leading research institutions and technology hubs that offer opportunities for collaborative R&D in next-generation battery technologies. By working with these institutions, Korean firms can accelerate innovation and bring advanced battery solutions to market more quickly.

These strengths notwithstanding, the United States also has a variety of constraining factors. Some of these dovetail with South Korea's strengths to create opportunities, while others limit the potential of smooth collaboration between the two countries. Despite its high demand for batteries, the United States has limited battery-manufacturing infrastructure compared with other regions, especially China. This shortage of domestic production facilities opens opportunities for Korean companies to establish and expand battery plants in the United States to meet local demand and benefit from incentives. Similarly, the U.S. supply chain for key battery components, such as anodes, cathodes, and separators, is underdeveloped. These gaps necessitate imports, often from Asia, making it challenging for U.S. companies to build a fully domestic battery supply chain. Korean companies with established component production capabilities can fill these gaps by localizing part of their supply chain in the United States.

At the same time, high labor and operational costs in the United States can reduce the profitability of battery manufacturing. While this can deter some investments, Korean companies bring process efficiency and lean manufacturing expertise, which can help manage these costs and improve production efficiency in U.S.-based plants.

Another challenge arises from U.S. policy uncertainty. In the past, U.S. energy and environmental policies have fluctuated significantly between administrations. Such policy shifts create uncertainty for long-term investment. Whereas recent bipartisan support for renewable energy and battery technology has created a more stable environment, encouraging Korean firms to invest in larger-scale projects, leadership changes could significantly alter this situation.

The Current Landscape of U.S.-ROK Cooperation on Batteries

Existing partnerships. A significant portion of U.S.-ROK battery cooperation is rooted in partnerships between Korean battery manufacturers and major U.S. automakers. These collaborations aim to expand EV production and secure a steady supply of high-quality batteries. For instance, LG Energy Solution has a well-established partnership with GM through their joint venture Ultium Cells. The companies are building multiple battery plants in the United States, including facilities in Ohio and Tennessee, which will supply GM's EV lineup. This collaboration is central to GM's goal of transitioning to an all-EV fleet by 2035. Likewise, SK On, a subsidiary of SK Innovation, has partnered with Ford to create BlueOval SK, a joint venture with a planned investment of over $11 billion.[19] BlueOval SK is building large-scale battery plants in Tennessee and Kentucky, which will provide batteries for Ford's EVs. Samsung SDI has likewise entered into a joint venture with Stellantis to establish a battery plant in Indiana. This facility, scheduled to begin production by 2025, will support Stellantis's electrification goals across its brands, which include Jeep, Chrysler, and Dodge.

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[19] David Shepardson, "U.S. Finalizes $9.63 Billion Loan for Ford, SK On Joint Battery Venture," Reuters, December 16, 2024, https://www.reuters.com/business/autos-transportation/us-finalizes-963-billion-loan-ford-sk-joint-battery-venture-2024-12-16.

Yet the bilateral partnership is not limited to Korean companies supplying batteries to U.S. automakers. U.S.-ROK collaboration is also expanding into storage systems for renewable energy. Korean companies like LG Energy Solution are working with U.S. providers to develop large-scale battery-based energy storage solutions, which are essential for managing intermittent renewable energy sources like wind and solar. Korean companies have also been partnering with U.S. universities and research institutes to advance next-generation battery technologies, including solid-state and lithium-sulfur batteries. For example, collaborations between LG and the University of California system focus on battery chemistry innovation, while Samsung and MIT are researching materials for high-energy-density batteries.[20]

Supply chain integration. Efforts to establish a resilient battery supply chain in North America have incentivized Korean firms to establish local production facilities. These plants not only meet the U.S. production requirements in the IRA but also reduce transportation costs, tariffs, and vulnerability to international supply chain disruptions.

Korean companies are increasingly investing in the local production of key battery components, such as anodes, cathodes, and separators, to meet domestic content requirements. LG Energy Solution and SK On, for example, have announced plans to source more materials and components within the United States that will help fulfill requirements for tax incentives under recent U.S. legislation. To further integrate the battery supply chain, Korean companies are forming partnerships with U.S.-based mining companies to secure a steady supply of critical minerals like lithium and nickel. For instance, SK Innovation has explored supply contracts with American lithium producers, while LG Energy Solution is collaborating with Canadian and Australian mining firms with operations in North America.

Recycling has also emerged as an area of supply chain integration where U.S. and Korean companies can cooperate. Korean companies bring advanced recycling technologies, while U.S.-based recycling firms provide collection and material-recovery services.

U.S. companies like Li-Cycle have partnered with Korean firms to create circular supply chains.[21] Li-Cycle's North American facilities process end-of-life batteries, recovering materials that can be reused in new battery production. This closed-loop model reduces reliance on imported raw materials and aligns with the U.S. goal of building a self-sustaining battery ecosystem. Both the U.S. and ROK governments support the development of recycling facilities to reduce waste and dependency on raw materials. Korean companies are establishing recycling centers in the United States with technologies that maximize the recovery of key battery metals.

In conclusion, the current landscape of U.S.-ROK cooperation on batteries is robust, with strong policy support in both countries and growing investment in localized production. As U.S. demand for EVs and renewable energy storage rises, Korean battery companies have positioned themselves as key players in this transition by partnering with U.S. automakers, establishing U.S. production facilities, and adapting their supply chains to meet local requirements.

With a new administration in the United States, however, some reconfiguration of key policy measures on batteries may be forthcoming. There have been reports that the Trump administration

[20] "A New Solid-State Battery Surprises the Researchers That Created It," LG Energy Solution, Press Release, September 23, 2021, https://news.lgensol.com/company-news/press-releases/872; and David L. Chandler, "Going Solid-State Could Make Batteries Safer and Longer-Lasting," MIT News, August 17, 2015, https://news.mit.edu/2015/solid-state-rechargeable-batteries-safer-longer-lasting-0817.

[21] "Li-Cycle Completes Commercial Agreements with LG Chem and LG Energy Solution, Who Have Recognized Li-Cycle as Their Preferred Lithium-Ion Battery Recycling Partner in North America," Businesswire, https://www.businesswire.com/news/home/20220421005091/en/Li-Cycle-Completes-Commercial-Agreements-with-LG-Chem-and-LG-Energy-Solution-who-have-Recognized-Li-Cycle-as-their-Preferred-Lithium-ion-Battery-Recycling-Partner-in-North-America.

might repeal a variety of tax credits available through the IRA, which could negatively affect the business environment for battery manufacturing and investment. U.S.-ROK cooperation on batteries needs to expand further as both countries desire a more resilient, sustainable, and self-sufficient battery ecosystem.

Policy Options for Enhancing the Depth and Breadth of U.S.-ROK Cooperation on Batteries

Charlie Vest and Sangmin Shim

As this chapter has highlighted, new battery technologies will play a central role across many sectors, and U.S. and ROK leadership in these areas will enable both countries to minimize risks that could arise from overreliance on a single producer dominating the market. The following policy options and related actions could help elevate bilateral cooperation between the United States and South Korea to a higher level. Not only could they strengthen the already sturdy collaborative business relationship, but they might also serve as a template for the two nations to collectively build strong and long-lasting industrial alliances.

Developing Next-Generation Technologies Together

Joint R&D initiatives. The United States and South Korea could establish joint R&D programs focused on next-generation battery technologies such as solid-state, lithium-sulfur, and lithium-air batteries. These technologies promise higher energy density, faster charging ability, and improved safety compared with conventional lithium-ion batteries. Collaborative R&D could leverage the strengths of each country, such as the United States' research institutions (e.g., MIT and Argonne National Laboratory) and South Korea's corporate R&D centers at LG, Samsung, and SK Innovation.

Innovation hubs and tech incubators. Setting up joint innovation hubs in both countries could accelerate the commercialization of emerging technologies. By pooling resources, these hubs could support start-ups and smaller companies, encouraging innovation in battery management systems, recycling processes, and advanced materials.

Government-funded research. Increased government funding through grants and public-private partnerships could accelerate innovation. The United States and South Korea could jointly fund projects with shared intellectual property rights, with a focus on technologies that reduce reliance on scarce materials or enhance battery-recycling capabilities. For example, co-investing in solid-state batteries could position both countries as leaders in a technology projected to transform the EV industry within the next decade.

Supply Chain Resilience

Localized production and diversification of raw materials. To enhance supply chain resilience, the United States and South Korea could work together to diversify sources of raw materials like lithium, nickel, and cobalt. Joint investments in mineral-rich countries and regions such as Australia, Canada, and Latin America could create secure, diversified supply lines less vulnerable to geopolitical tensions.

Bilateral agreements for critical materials. Both countries could establish bilateral agreements to secure access to critical minerals through shared sourcing, processing, and stockpiling. For instance, the ROK's advanced processing techniques and the United States' abundant mineral reserves could be combined to ensure steady access to refined materials without relying on third-party countries.

Expansion of battery-recycling facilities in North America. A resilient supply chain should include recycling facilities to recover materials like cobalt, nickel, and lithium from used batteries. Korean companies already experienced in battery recycling could partner with U.S. firms to set up advanced recycling plants in North America, enhancing resource circularity and reducing the demand for virgin materials.

Building on progress from the IRA. The IRA provides a strong foundation for promoting EV manufacturing in the United States, while addressing national security risks posed by suppliers from countries of concern. Repealing or weakening the IRA would reduce U.S. leverage in attracting foreign investment in battery manufacturing from allied countries.

Regulatory Harmonization

Setting international battery standards. By working together to set international standards for battery performance, safety, and sustainability, the United States and South Korea could lead the global battery industry toward greater consistency and interoperability. In particular, standardizing battery life, charging rates, and recycling efficiency can help companies reduce costs and ensure that batteries meet the same quality benchmarks worldwide.

Mutual recognition of certifications. If the United States and the ROK were to agree to recognize each other's certifications for battery products, manufacturers could enter each other's markets more easily, avoiding repetitive and costly certification processes. This would be especially beneficial for EV manufacturers that rely on batteries meeting specific standards for safety and durability.

Establishment of joint regulatory frameworks for new technologies. For next-generation batteries like solid-state batteries, which have different chemical properties and safety profiles, the United States and South Korea could develop regulatory frameworks together. This proactive approach would help streamline the introduction of new technologies into both markets, fostering faster adoption and creating a competitive edge for U.S.-ROK battery innovations.

Workforce Development and Knowledge Exchange

Joint education and training programs. Collaborative programs between Korean universities and U.S. institutions could help train a new generation of battery scientists and engineers. Exchange programs, internships, and cooperative research initiatives would build a skilled workforce well-versed in both countries' technologies, manufacturing processes, and regulatory requirements.

Skilled worker mobility agreements. To facilitate the movement of skilled workers between the United States and South Korea, both governments could develop visa programs tailored to the battery industry. This would allow Korean engineers and technicians to work in the United States and vice versa, helping fill labor gaps and promote knowledge exchange.

Partnerships between industry and academia. By linking universities and technical institutes with industry leaders, both countries could offer hands-on training programs in battery research, production, and recycling. For example, partnerships between institutions like Stanford University and the Korea Advanced Institute of Science and Technology could provide research opportunities in battery technology, cultivating workforce expertise in both nations.

Enhancing U.S.-ROK cooperation on batteries requires a comprehensive approach that combines joint R&D, supply chain resilience, regulatory alignment, workforce development, and targeted investment incentives. These measures could create a robust framework that capitalizes on both countries' strengths, mitigates their weaknesses, and fosters an enduring, mutually beneficial partnership. Through collaborative innovation and policy alignment, the United States and South Korea could jointly lead the global battery industry, accelerating the transition to clean energy and strengthening economic ties.

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A Policy Framework for Strengthening U.S.-ROK Collaboration on Biotechnology

Hyun-Chul Kim and Michelle Rozo

EXECUTIVE SUMMARY

This chapter examines U.S. and South Korean approaches to the development of the biotechnology industry and proposes pathways to greater cooperation on advancing shared objectives and minimizing potential risks.

MAIN ARGUMENT

Biotechnology—the application of biological processes to develop new products and capabilities—is already used extensively to improve health, agriculture, energy, and industry. Both the U.S. and the Republic of Korea (ROK) have significant interests in developing their biotech sectors to capitalize on positive outcomes, including economic growth, advances in healthcare, and improvements to food security. With advances in engineering tools applied to biology, coupled with artificial intelligence and automation, emerging biotechnology is on the cusp of unleashing a wave of scientific, economic, and military innovations. At the same time, advances in biotechnology will introduce significant new threats and challenges as the risk of misuse also grows. Given the scale and scope of its potential economic and national security implications, biotechnology stands at the forefront of the era of strategic competition. Strengthening U.S.-ROK cooperation on biotech development and use in ways that align with shared values will benefit both countries. Working together with key allies and like-minded partners will be essential in shaping related standards and norms, as well as for mitigating risks from malign actors.

POLICY IMPLICATIONS

- Biotechnology is an accelerating domain of global competition, and yet policymakers in Washington have not prioritized this sector in the same way that they have artificial intelligence and semiconductors.
- Market and innovation cooperation drives existing U.S.-ROK partnerships, enhancing biotech development, improving global market access, and addressing security risks collaboratively.
- Data collaboration and regulatory harmonization are two key areas where the U.S. and South Korea can make meaningful progress through collaborative efforts.
- Strategic cooperation on the biomanufacturing supply chain between the U.S. and ROK aligns with both nations' interests and addresses an urgent need.
- Delays or lack of decisive action in advancing strategic biotech collaboration between the U.S. and allies such as South Korea risks replicating challenges seen in other advanced technology domains, like semiconductors, where significant investments and trade measures were required to regain competitive advantages.

This chapter examines U.S. and South Korean approaches to developing the biotechnology industry in a safe and effective manner that will benefit both countries. In the first section of the chapter, Hyun-Chul Kim provides insight into the strengths and weaknesses of the biotech industry in the Republic of Korea (ROK). He also examines the policies and strategies the ROK government has implemented to facilitate advancements in the industry domestically and to improve cooperation internationally. He emphasizes that South Korea's biotech sector is emerging as a global leader, with notable advancements in patents, clinical trials, and research and development, alongside significant contributions to the biomanufacturing and biosimilar markets. Furthermore, he highlights that the ROK's strategic partnerships with the United States aim to enhance innovation, supply chain resilience, and data sharing to address global health challenges and foster technological growth. In the second section, Michelle Rozo shares the U.S. perspective on biotechnology, highlights the expanding application of biotechnology across an increasing range of sectors and industries, and notes that Washington now views it as an accelerating domain of global competition. In the final section, the authors jointly consider policy options for advancing U.S.-ROK cooperation on the development of biotechnology.

Biotechnology in South Korea[1]

Hyun-Chul Kim

The ROK's Technological and Industrial Competitiveness in Biotechnology

The ROK is distinguished globally for its competitiveness in biotechnology, a sector pivotal to the national economy. Over the five-year period from 2017 to 2021, South Korea secured the twelfth position worldwide in the number of Science Citation Index papers published in biotechnology, reflecting its active research environment. The ROK also holds a significant share (around 6%) of biotech patents in the United States, demonstrating its innovative contributions to the global biotech landscape.[2] According to the 2024 Nature Index, the country ranks fourteenth in biological sciences.[3] Focusing specifically on new drug development, South Korea boasts the third-largest R&D pipeline globally, holding just over 14% of the market in 2024, a share comparable to the United Kingdom's.[4] In clinical trials for new drugs, South Korea matches Japan with a 4% share of ongoing global clinical pipelines.[5]

As of 2023, South Korea's capital city, Seoul, produced the highest number of registered clinical trial sites globally for seven consecutive years. Following the Covid-19 pandemic, the ROK experienced a surge in bio-health product exports, which ranked among the top ten export categories in the first half of 2024.[6] The biotech industry has been recognized as one of the six core

1 This section is authored by **Hyun-Chul Kim**, who is the director general of R&D and innovation at the Korea Health Industry Development Institute (KHIDI).

2 Ministry of Science and ICT of the Republic of Korea (ROK) and National Center for Biotechnology Policy Research, *Biotechnology in Korea 2024* (Seoul, 2024), https://vitalkorea.kr/uploads/trend/0715_Biotechnology%20in%20Korea%202024.pdf.

3 "Biological Sciences Country Outputs," Nature Index, 2024, available at https://www.nature.com/nature-index/country-outputs/generate/biological-sciences/global.

4 Citeline, "Pharma R&D Annual Review 2024," April 2024, https://www.citeline.com/-/media/citeline/resources/pdf/white-paper_annual-pharma-rd-review-2024.pdf.

5 IQVIA Institute, "Global Trends in R&D 2024," February 2024, https://www.iqvia.com/insights/the-iqvia-institute/reports-and-publications/reports/global-trends-in-r-and-d-2024-activity-productivity-and-enablers.

6 Ministry of Trade, Industry and Energy (ROK), "July Export-Import Trends," August 1, 2024.

advanced strategic industries under the National Advanced Strategic Industries Act of February 2022, underscoring its critical role in the ROK's innovation framework.

Recent enhancements in the ROK's competitiveness in biotechnology and biomanufacturing are being strategically aligned with national security objectives. The Covid-19 pandemic underscored the essential role of biotechnology, as challenges in the supply of vaccines and other critical medical products highlighted the industry's integral role in national security. The ROK was a frontrunner in granting approvals for Covid-19 diagnostic kits, which established its early diagnostic capabilities and positioned the country as a model for pandemic response.[7] Further, the ROK is intensifying efforts to achieve self-sufficiency in mRNA vaccine production in preparation for future pandemics.

The ROK's growing biomanufacturing capabilities are also crucial for securing the global biotech supply chain, which has become a primary concern for biosecurity. Notably, Samsung Biologics ranks fourth among the top ten global biologics contract development and manufacturing organizations (CDMOs),[8] and the ROK's biopharmaceutical production capacity is the second largest globally as of 2021.[9]

The ROK has also pioneered the biosimilar market (biologic medication similar to what has already been approved for the market), with the biotech company Celltrion receiving the world's first approval for a biosimilar product.[10] This has stimulated competition in the biopharmaceutical market, reducing prices and enhancing patient access to high-cost biomedicines. Looking ahead, biotechnology is expected to drastically reduce the costs associated with the development, manufacturing, and logistics of medical products through digital transformation, thereby mitigating rising healthcare costs, enhancing the quality of care, and contributing to a sustainable health system.

The ROK's Strategic Position in the Global Biotech Ecosystem

The biotech industry is a well-established sector within the global open innovation ecosystem, characterized by its significant scientific foundation and the economic value of its scientific outputs.[11] Anchored in foundational research primarily conducted by universities, this sector plays a pivotal role in driving scientific discoveries and fueling the creation of innovative technologies and start-ups.[12] For science to be linked to business and for innovative technologies to scale up, the establishment of start-ups through venture capital, accelerators, and collaboration between academia and industry is crucial. The biotech sector's intrinsic high-risk, high-reward nature demands an innovation system that encourages private-sector participation by sharing the inherent risks associated with advancements. The role of small and medium-sized enterprises (SMEs) is particularly significant in the United States. These entities constitute 99% of the biotech

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7 U.S. Food and Drug Administration, "South Korea's Response to COVID-19," 2021.

8 Alex Philippidis, "Top 10 Contract Development and Manufacturing Organizations 2024," *Genetic Engineering and Biotechnology News*, August 23, 2024, https://www.genengnews.com/topics/bioprocessing/top-10-contract-development-and-manufacturing-organizations-2024.

9 Marian Chu, "South Korea Has a Biologic Production Capability of 385,000 Liters, Placing It as the Second Largest in the World," BioWorld, September 27, 2023, https://www.bioworld.com/articles/701326-south-korea-rolls-out-bio-economy-20-to-top-global-biologics-biosimilar-market.

10 Remsima, an autoimmune treatment developed by Celltrion, was the world's first biosimilar to receive marketing authorization from the European Medicines Agency in August 2013.

11 Gary P. Pisano, *Science Business: The Promise, the Reality, and the Future of Biotech* (Cambridge: Harvard Business Review Press, 2006).

12 Ibid.

industry and lead 76% of the clinical trial drug pipelines, showcasing their critical position in advancing medical R&D.[13]

Clinical research, pivotal for validating innovations intended for human use, depends heavily on integration with hospitals, where critical data and insights are derived directly from medical practice. The development phase, often marked by high costs, benefits from a strategic collaboration framework where SMEs' innovations are globally commercialized by larger corporations, including multinationals. The United States exemplifies this with its robust federal support for basic research, dense network of top-tier universities and hospitals, leading venture capital ecosystem, and advanced legal and regulatory framework for intellectual property and the safety of bioproducts, making the country a leader in global biotech innovation. In 2023 the U.S. Food and Drug Administration (FDA) approved 55 new drugs, 41% more than the European Medicines Agency. U.S. biotech firms accounted for 58% of these approvals, underscoring the United States' dominant influence in the global biotech sector.

Concurrently, the South Korean biotech landscape exhibits vibrant dynamism, with over 3,000 start-ups, including nearly 2,000 established between 2017 and 2021.[14] Pharmaceutical and biotech firms constitute 16.3% of the market capitalization on the KOSDAQ, reflecting significant growth analogous to the U.S. NASDAQ.[15] The ROK ranks fifth globally in the size of venture capital funding as of 2023,[16] with substantial investment directed toward the biotech and healthcare sectors.[17]

The ROK's biotech sector continues to expand its global footprint, with strategic partnerships enhancing its role in the international bio-innovation network. The country is a trailblazer in the biosimilars market, holding significant shares in U.S. FDA approvals.[18] It is expected to maintain this position as a global leader in biopharmaceutical production capacity, driven by recent increases in investments by Korean companies in biopharmaceutical manufacturing facilities. Additionally, the increasing number of SMEs in the CDMO space and rising investments from various industry giants are transforming the ROK into a critical hub for biomanufacturing and supply chain management, amplifying its strategic importance in the global biotech landscape.

Strategic Dynamics and Policy Initiatives in the U.S.-China Biotech Rivalry: Implications for the ROK

The global biotech industry is increasingly influenced by strategic competition, particularly between the United States and China. China's pharmaceutical industry has significantly expanded its global value share from 5.6% in 2002 to 24.2% in 2019, reflecting a marked improvement in innovation and an expanding international presence.[19] Concurrently, China has articulated its ambition to elevate its bioeconomy through the announcement of a five-year bioeconomy plan in

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13 Bio and TEConomy Partners, "The Bioscience Economy: Propelling Life-Saving Treatments Supporting State and Local Communities," January 2021.

14 Korea Research Institute of Bioscience and Biotechnology, "Statistics on Domestic Bio Ventures and Small Businesses as of 2021," 2023.

15 Data as of December 30, 2024.

16 "Advanced Venture Investment Market Strategies for Globalizing Venture Startups," Ministerial Meeting on Economic Affairs, October 2024.

17 As of 2023, the size of domestic venture capital investment in South Korea in the biotech and healthcare sectors amounted to 10 trillion won and 913.3 billion won, respectively, ranking fifth globally after the United States, China, the United Kingdom, and India. During the first half of 2024, 15.6% of domestic venture capital investment in South Korea was allocated to these sectors. "2024 First Half-Year Venture Investment 5.4 Trillion Won, Fund Formation 5.1 Trillion Won," Ministry of SMEs and Startups (ROK), September 21, 2024.

18 Among the biosimilars approved by the U.S. FDA, 13 products are from Korean companies, making South Korea the second-largest contributor after the United States, which has 24 approved products. Philippidis, "Top 10 Contract Development and Manufacturing Organizations 2024."

19 Sandra Barbosu, "How Innovative Is China in Biotechnology," Information Technology and Innovation Foundation, August 2024, https://www2.itif.org/2024-chinese-biotech-innovation.pdf.

May 2022. This strategic plan, the first of its kind, aims to fuse biotechnology with information technology, accelerate pharmaceutical advancements, and expand China's bioeconomy, focusing on bioagriculture, biomass utilization, and national biosecurity risk management.[20]

In response, the United States has intensified its strategic and legal efforts to counter China's rapid advancements in biotechnology and to bolster partnerships with allied nations. The U.S. Congress passed the CHIPS and Science Act in 2022, which, in addition to its better-publicized efforts to promote the semiconductor industry, included funding for R&D in advanced technologies. Specifically, Title 4 of the "Research and Innovation" section addresses threats to the U.S. bioeconomy posed by foreign adversaries using both legal and illicit means to acquire critical U.S. technologies, including biological data. This legislative measure underscores the need to safeguard the U.S. bioeconomy to maintain national security and economic competitiveness.

To operationalize these goals, the White House launched the National Biotechnology and Biomanufacturing Initiative in September 2022. The initiative strategically focuses on utilizing biotechnology to strengthen supply chains, expand domestic biomanufacturing, foster innovation, broaden the bioproduct market, and train the next generation of biotechnologists. This initiative also includes efforts to innovate regulatory frameworks to enhance biotech product accessibility, establish bioeconomic standards, promote biosecurity innovation, and facilitate data sharing, with an allocation of $2 billion to support these endeavors.[21]

In a further move to reduce dependency on Chinese biotech inputs and strengthen domestic capabilities, the U.S. House of Representatives passed the BIOSECURE Act in September 2024. If adopted, the proposed legislation would prohibit U.S. entities from engaging with Chinese biotech firms identified as security risks, including major CDMO companies such as WuXi Apptech and WuXi Biologics, as well as genomics firms such as BGI Genomics and its spin-off MGI Tech. The law would compel U.S. pharmaceutical companies to choose between partnering with Chinese entities and securing U.S. government contracts, creating significant operational dilemmas given that many major U.S. companies, such as Pfizer, rely on Chinese CDMOs. A survey from the Biotechnology Innovation Organization found that 79% of the 124 biopharmaceutical companies surveyed have contractual ties with Chinese firms, and finding alternatives could pose substantial challenges within the eight-year grace period provided by the law.[22]

These developments open a strategic window for enhanced U.S.-ROK collaboration in biotechnology, necessitating a nuanced approach from South Korean firms and policymakers. Increased cooperation could require a recalibration of the ROK's interactions with China, potentially leading to economic and trade retaliations from Beijing. Thus, the ROK finds itself in a delicate position, needing to balance its biotech engagements with the United States and China amid evolving geopolitical dynamics.

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20 "Wo guo shoubu shengwu jingji wunian guihua fabu jujiao ni guanzhu de 'yishimeian'" [The First Five-Year Plan for China's Bioeconomy Released, Focusing on the "Healthcare, Food, Beauty, and Safety" You Care About], *People's Daily*, May 10, 2022, from http://finance.people.com.cn/n1/2022/0510/c1004-32418446.html.

21 "The United States Announces New Investments and Resources to Advance President Biden's National Biotechnology and Biomanufacturing Initiative," White House, Fact Sheet, September 14, 2022.

22 "Impact of Biosecure Act on U.S. Biotech Industry: Survey Results," Biotechnology Innovation Organization, Press Release, 2024.

ROK National Strategies for Bio-Diplomacy

In 2022 the ROK government's investment in biotechnology was 5.2 trillion won ($4.13 billion), representing 18.1% of the total government investment in science and technology.[23] This was the highest share among the six designated priority technologies. In March 2023 the Special Act on the Fostering of National Strategic Technology identified advanced biotechnology as one of twelve national strategic technologies. The advanced biotech sector includes four key focus areas: synthetic biology, gene and cell therapy, infectious disease vaccines and treatments, and digital health data analysis and utilization. The ROK government has intensified policy, diplomatic, and strategic efforts to support this strategy. In April 2024, for example, it announced the Biomanufacturing Innovation Strategy to propel the ROK to become the world's leading biopharmaceutical manufacturing hub.

The Boston-Korea Project—a flagship project to strengthen strategic scientific and technological cooperation in the biotech sector between the ROK and the United States—was initiated in 2024, spearheaded by three ministries: the Ministry of Health and Welfare, the Ministry of Science and ICT, and the Ministry of Trade, Industry and Energy. The project involves various sub-projects, including training global talent such as physician-scientists, establishing biotech hubs in the United States, and conducting joint R&D with major universities and research institutes.

In January 2024 the ROK established the Office of Science and Technology Policy in the Presidential Office, and a dedicated advanced biotech secretary was appointed directly under it. To integrate and link biotech strategies and support systems across government departments, the ROK government announced the establishment of the National Bio Committee following the Cabinet's approval of the related presidential decree on October 29, 2024. In April 2024 the Science and Technology Policy Council announced the Advanced Biotechnology Initiative at a joint public-private meeting, which is aimed at protecting and strategically fostering the advanced biotech sector, alongside artificial intelligence (AI), semiconductor, and quantum technologies. The initiative includes eleven technological innovation tasks to foster digital biotechnology, biomanufacturing innovation, and biomedical innovation, as well as ten foundational tasks to develop key talents and industrial ecosystems, including digital infrastructure research, global cooperation, and regulatory innovation.

In July 2024 the Ministry of Science and ICT announced the Global R&D Strategy Map for Advanced Biotechnology with leading countries, including the United States. The strategy prioritizes collaboration in areas such as synthetic biology, gene and cell therapies, and digital health technologies. From a biosecurity perspective, such collaboration is intended to strengthen the U.S.-ROK alliance by enhancing cooperation in the biotech sector. In April 2023, during an event commemorating the 70th anniversary of the alliance, the presidents of both countries committed to deepening and expanding cooperation on critical and emerging technologies, including the establishment of a dialogue led by their national security advisers. Additionally, they emphasized cooperation in AI, biotechnology, AI-enabled medical products, and biomanufacturing.[24] As a follow-up, in December 2023 the two governments launched the Next Generation Critical and Emerging Technologies Dialogue, where biotechnology and

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23 Ministry of Science and ICT (ROK) and Korea Institute of S&T Evaluation and Planning, "2022 National Research and Development Project Survey and Analysis Report," November 2023.

24 "Leaders' Joint Statement in Commemoration of the 70th Anniversary of the Alliance between the United States of America and the Republic of Korea," White House, April 26, 2023.

biomanufacturing are treated as one of the six major strategic technology areas.[25] Their joint statement includes initiatives focused on biomanufacturing collaboration, Track 1.5 channels to enhance the resilience of the global biopharmaceutical supply chain, and biomedical research cooperation related to infectious diseases and immunology. Finally, as part of the dialogue, from 2024 onward, the ROK Ministry of Science and ICT and the U.S. National Science Foundation plan to jointly support five collaborative research projects on the bioeconomy.

The Potential Benefits of Greater U.S.-ROK Cooperation between the Tech Industries

The ROK's domestic biotech market, which constitutes a modest 2% of the global market, faces challenges in achieving economies of scale through domestic demand alone. Robust government support, along with heightened private investment from venture capital, positions Korean biotech start-ups and SMEs among the global leaders in innovation. Korean firms have reached a level in biotech and pharmaceutical patent applications via the Patent Cooperation Treaty that is similar to Japan and follows China and the United States.[26] However, options for biotech start-ups to exit via initial public offerings are limited, and sustaining listings on stock markets like KOSDAQ poses significant sustainability challenges. There are no Korean biopharmaceutical companies within the global top 50 capable of commercializing innovative technologies on a global scale. Moreover, only one innovative drug developed independently has been FDA-approved, highlighting the lack of experience in medical product development. Conversely, the United States holds a leading position in the biotech sector, in terms of both market size and technological competitiveness. Recent collaborations, such as between Yuhan Corporation and Janssen, have led to the FDA approval of innovative cancer drugs surpassing the efficacy of existing treatments, illustrating the tangible benefits of strategic cooperation with U.S. global biotech firms.

Korean biotech firms are actively entering the U.S. market through various channels, including by establishing research facilities in the United States, creating local subsidiaries and joint ventures, and acquiring U.S. biomanufacturing plants. This activity underscores the vibrancy of ROK investment in the United States. Given high dependence on SMEs in the U.S. biotech industry—where they constitute 99% of companies within the sector[27]—and the increasing difficulty of utilizing Chinese biotech partners, the ROK's biotech capabilities present a promising alternative. If ROK biotech start-ups and SMEs can supply innovative technologies, and U.S. big biopharma companies can commercialize these technologies, significant synergies could be created in drug development competitiveness. Such strategic cooperation would enable ROK biotech firms to bolster their drug development capabilities and secure entry into the U.S. market, while U.S. big biopharma companies could substantially enhance their pipelines and market competitiveness. Additionally, the ROK's development and entry of biosimilars into the U.S. market could induce price competition in the high-cost biopharmaceutical market, thereby contributing to the objectives of the Inflation Reduction Act by reducing drug prices.

From a biosecurity perspective, the ROK is already an important strategic partner for the United States. Given the significant Chinese share in the biopharmaceutical and medical device supply chains, diversification through international cooperation is necessary. During the Covid-19

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[25] "Launching the U.S.-ROK Next Generation Critical and Emerging Technologies Dialogue," White House, Fact Sheet, December 8, 2023.

[26] Alessandra Zimmermann, "U.S. R&D and Innovation in a Global Context: The 2024 Data Update," American Association for the Advancement of Science, April 2024, https://www.aaas.org/news/us-rd-and-innovation-global-context-2024-data-update.

[27] Bio and Teconomy Partners, "The Bioscience Economy."

pandemic, U.S. shortages in vaccines, diagnostic kits, and sanitation supplies arose due to supply chain disruptions in China and India. In response, the ROK played a crucial role in the medical supply chain. Samsung Biologics is a global leader in terms of biopharmaceutical production capacity,[28] while large companies like Celltrion, along with smaller CDMOs such as Binex, CHA Biotech, SK Pharmteco, and ST Pharm, also demonstrate strong global competitiveness. The United States, however, still depends heavily on China and requires substantial time to completely shift and build a global biomanufacturing supply chain. Strategic cooperation on the biomanufacturing supply chain between the United States and ROK thus aligns with both nations' interests and addresses an urgent need.

The Critical and Emerging Technologies Dialogue also emphasizes cooperation between the two countries on the treatment of infectious diseases and cancer. Biomedical data cooperation is one extremely promising area of synergy. For instance, the ROK, which has a high incidence rate of stomach cancer, could provide data on stomach cancer to the United States, which has a low rate. Conversely, skin cancer is rare in the ROK but common in the United States. Considering the differences in disease incidence rates, mutual data supplementation could enhance research collaboration, leading to impactful outcomes in related R&D. Starting from 2024, the ROK aims to construct a biobank of data from one million Koreans under the National Project of Bio Big Data, following a standard system nearly identical to that of the United States' All of Us Research Program, thus ensuring high interoperability. If biobank data sharing between the two countries is enhanced, the United States could significantly expand its East Asian biomedical data, contributing to health equity among Americans of East Asian descent, while the ROK could gain access to biomedical data on Caucasians, African Americans, and Hispanics. Data sharing between the two countries could thus enhance understanding of health and disease across diverse racial groups and drive innovation in medical technologies spanning prevention, diagnosis, treatment, and management. The United States faces a dilemma where the implementation of the BIOSECURE Act is likely to increase the cost of pharmaceutical production and lead to inevitable price hikes, while the Inflation Reduction Act mandates reasonable pricing adjustments for medications. If the market for biosimilars expands and the ROK's entry into the U.S. biosimilar market accelerates, drug prices could decrease due to competitive pricing, significantly contributing to health equity for U.S. citizens.

28 "Samsung Biologics, Massive Order Secured; Lift TP," Mirae Asset Securities Equity Research, October 22, 2024, https://securities.miraeasset.com/bbs/download/2131723.pdf?attachmentId=2131723.

A U.S. Perspective on Biotechnology[29]

Michelle Rozo

Biotechnology—the application of biological processes to develop new products and capabilities—is already used extensively to improve health, agriculture, energy, and industry. With advances in engineering tools applied to biology, coupled with artificial intelligence and automation, emerging biotechnology is on the cusp of unleashing a wave of scientific, economic, and military innovations. Presenting both immense potential for economic growth and significant risk of misuse, biotechnology stands at the forefront of the era of strategic competition. Policymakers in Washington have not yet sufficiently prioritized biotechnology—perhaps in part because it is a complex technology with a diffuse global supply chain and a wide range of policy implications. The United States and its partners and allies will need to act, and do so closely together, to stay at the leading edge of the technology.

Biotechnology Is a Key Emerging Technology

Biotechnology is advancing rapidly, owing to a series of breakthroughs in the understanding and manipulation of biology. For example, gene-editing systems such as CRISPR-Cas9 have increased the accuracy and efficacy of genome engineering. Biotechnology is also converging with other emerging technologies like AI, automation, and quantum computing. AI offers the ability to make sense of the complexity within biology, to process and interpret vast amounts of biological data, and to inform researchers on how to build biological systems with specific characteristics and capabilities. Robotics and automated equipment are standardizing and accelerating research and production. Quantum technologies are being explored for improved imaging and sensing of biological systems, as well as to better control the behavior of biomolecules.[30] As these technologies mature, coordinated support from both the public and private sectors will be necessary to ensure synergistic development, deployment, and usage.

In 2023 the global biotech market was valued at $1.55 trillion and is projected to grow to $3.88 trillion by 2030.[31] It has the potential to affect every sector of the economy. Biotechnology stands to revolutionize medicine, making it possible to create more drugs to treat more patients. Biotechnology can improve food security with diverse sources of healthier, heartier, and more nutritious food. It is already diversifying the energy sector, providing new opportunities for sustainable fuels. And it could usher in a new mode of manufacturing, unconstrained by the availability of raw materials, to offer domestic routes of production for critical inputs to commercial and defense supply chains.

As with other emerging technologies, biotechnology has its risks. It could be used by state or nonstate actors to affect warfighting.[32] Biology is self-replicating and interconnected, so a biological event occurring in one part of the world could spread geographically and across

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[29] This section is authored by **Michelle Rozo**, who is vice-chair of the National Security Commission on Emerging Biotechnology. The views expressed here are the views of the author and do not necessarily reflect the views and positions of the National Security Commission on Emerging Biotechnology.

[30] Nicolas P. Mauranyapin, Alex Terrason, and Warwick P. Bowen, "Quantum Biotechnology," *Advanced Quantum Technologies* 5, no. 9 (2022), available at https://arxiv.org/pdf/2111.02021.

[31] Zelie Petit, "The Strategic Imperative of Biotechnology: Implications for U.S. National Security," Center for Strategic and International Studies, September 27, 2024, https://www.csis.org/blogs/strategic-technologies-blog/strategic-imperative-biotechnology-implications-us-national.

[32] Luke J. Matthews et al., "Plagues, Cyborgs, and Supersoldiers: The Human Domain of War," RAND Corporation, Research Report, January 2024, https://www.rand.org/pubs/research_reports/RRA2520-1.html.

lineages. Given the tight linkages with human biological data and personal identifiable information, biotechnology could be used in ways that violate individuals' privacy or that are contrary to our norms and values, which can lead to public mistrust. Analysis suggests that 70% of the total potential impact of biotechnology could depend on consumer, societal, and regulatory acceptance.[33] International collaboration and coordination on shared normative frameworks, including principles that govern biotech usage, will be essential to support global development in ways that align with shared values.

While U.S. government agencies have long supported biotech R&D in areas that align with their agency mandate, it is clear that Washington views biotechnology as an accelerating domain of global competition. The Department of Defense named biotechnology as one of the critical technology areas vital to maintaining United States security in 2019.[34] President Joe Biden's national security advisor Jake Sullivan labeled "biotechnologies and biomanufacturing" as one of three families of technologies that will be of particular importance over the coming decade.[35] Moreover, the National Security Commission of Emerging Biotechnology was charged with providing policy recommendations to the U.S. Congress at the intersection of emerging biotechnology and national security by 2025. This growing recognition of the importance of biotechnology must now come with policy actions.

Washington is experienced with technology policy and has experimented with novel mechanisms in recent years to both promote and protect critical technologies alongside partners and allies. For example, the passage of the CHIPS and Science Act and appropriations of CHIPS funding have supported large loans for semiconductor companies looking to make advanced chips in the United States. The execution of export controls on the manufacturing equipment necessary to make leading-edge semiconductor chips, in concert with allies, demonstrated multilateralism in action. Yet biotechnology is very different from semiconductors, which could make implementation of technology policies challenging around the globe.

U.S. Gaps and Policy Priorities

The United States is home to many of the world's leading biotech companies and sits at the forefront of core disciplines like synthetic biology. The U.S. biopharma sector leads the world in market cap. However, biotech R&D still takes too long, and commercializing a product is too expensive. On average, moving a drug from discovery to market takes ten to fifteen years and costs $1 billion, with around a 90% failure rate.[36] Biotechnology has not yet hit its "ChatGPT moment," but the inflection point of the technology is approaching rapidly, especially due to the convergence with AI.

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33 McKinsey and Company, "The Bio Revolution: Innovations Transforming Economies, Societies, and Our Lives," Report, May 13, 2020, https://www.mckinsey.com/industries/life-sciences/our-insights/the-bio-revolution-innovations-transforming-economies-societies-and-our-lives#section-header-4.

34 John Cumbers, "'With Great Power Comes Great Responsibility'—Meet Alexander Titus, the Department of Defense's Head of Biotechnology," *Forbes*, September 24, 2019, https://www.forbes.com/sites/johncumbers/2019/09/24/with-great-power-comes-great-responsibility--meet-alexander-titus-the-department-of-defenses-head-of-biotechnology.

35 "Remarks by National Security Advisor Jake Sullivan at the Special Competitive Studies Project Global Emerging Technologies Summit," White House, September 16, 2022.

36 "Research & Development Policy Framework," PhRMA, https://phrma.org/policy-issues/Research-and-Development-Policy-Framework; Olivier J. Wouters, Martin McKee, and Jeroen Luyten, "Estimated Research and Development Investment Needed to Bring a New Medicine to Market, 2009–2018," *JAMA* 323, no. 9 (2020): 844–53, https://jamanetwork.com/journals/jama/fullarticle/2762311; and Duxin Sun et al., "Why 90% of Clinical Drug Development Fails and How to Improve It?" *Acta Pharmaceutica Sinica B* 12, no. 7 (2022): 3049–62, https://pubmed.ncbi.nlm.nih.gov/35865092.

U.S. and allied leadership over the future of biotechnology is not guaranteed, especially in the face of competition with the People's Republic of China (PRC). The PRC listed biotechnology as one of its seven strategic emerging industries in 2010 and has put in place a combination of policies designed to support the Chinese biotech industry over the last two decades. Following the same strategy for technological dominance that it used to develop 5G, the PRC has adopted policies that include relatively high R&D spending, talent recruitment programs, direct and indirect subsidies, support for state-owned enterprises, licit and illicit acquisition of intellectual property, and central government strategy and direction.[37] This approach appears to already be paying dividends. Key metrics indicate that the PRC is pulling ahead in biotech subfields such as biological manufacturing and synthetic biology.[38]

Making biology reliably easy to understand, manipulate, and scale through biotechnology and convergent technologies will require close collaboration between the public and private sectors. Today, most technology R&D occurs outside the U.S. government, but there remains a role for the government to play in developing assets and resources that can broadly benefit the entire biotech field, supporting commercialization, streamlining regulations, preventing misuse, and protecting the ecosystem from intellectual property theft and nonmarket distortions that threaten technology progressions.

First, the U.S. government needs to identify and empower a senior leader who is responsible for biotech coordination across the federal government. Biotechnology does not currently have the institutional structures and public workforce that other technologies like semiconductors or AI enjoy across the government. Elevating and prioritizing biotechnology is necessary for more effective execution of biotech policy. Next, the U.S. government must continue to support basic and applied R&D, as well as focus on advancing biological data—which is truly the "new oil"—to accelerate the convergence of biotechnology with AI. Biological data is a real limiting factor, and well-curated data sets are needed both at the level of basic biology (e.g., on subcellular components like RNA and proteins) and at the applied level (e.g., human clinical data sets) to accelerate design and development of specific products. Amassing large clinical data sets in the United States can be particularly challenging owing to the makeup of the U.S. healthcare sector and the segregated nature of health records. By supporting the development of accessible, standardized biological data sets, in a similar manner as was done through the Human Genome Project or the Protein Database, or as is underway through the All of Us Research Program, the U.S. government can enable rapid developments in the understanding of biology and the design of biotech capabilities and products.

The U.S. government should also support domestic manufacturing. Repeating the pattern seen in other industries like semiconductors, U.S. biotech companies are leaving the United States to scale up abroad because of a lack of domestic capacity. The existing U.S. infrastructure tends to be inaccessible, either because it is privately held or because it contains first-generation equipment and processes making the manufacturing less efficient and more cost-intensive. Biomanufacturing—or the production of biotech products—is still maturing. There are clear technological advances

37 Michelle Rozo, testimony at U.S.-China Economic and Security Review Commission hearing on "Current and Emerging Technologies in U.S.-China Economic and National Security Competition," Washington, D.C., February 1, 2024, https://www.uscc.gov/sites/default/files/2024-02/Michelle_Rozo_Testimony.pdf.

38 Jenny Wong-Leung and Dannielle Pilgrim, "ASPI's Critical Tech Tracker Updates: Biotechnology and the Tight Race towards the Top," Australia Strategic Policy Institute, Strategist, September 22, 2023, https://www.aspistrategist.org.au/aspis-critical-tech-tracker-updates-biotechnology-and-the-tight-race-towards-the-top.

in biomanufacturing that are under development but that need more progress and regulatory approval to be broadly applied. Therefore, in contrast to semiconductor funding, the U.S. government should focus additional support for biomanufacturing on midscale production and pilot facilities that can enable innovators to test out novel means of biomanufacturing alongside regulators.

The U.S. government should also work to address the gap in the capital stack for the commercialization of biotech products, particularly for nonmedical products. Potential market returns are much greater for pharmaceuticals than they are in other biotech sectors like agriculture or energy, which limits industry attention outside of biomedical applications. Novel biotech industrial products are also competing with cheap and abundant incumbents, such as commodity chemicals derived from petroleum, which makes winning out on cost alone extremely difficult. Financing and regulatory tools could adjust the cost for these products until the market catches up. The U.S. government could employ market-shaping measures for those products that provide a national security advantage, such as bio-based active pharmaceutical ingredients for supply chain resiliency. There are also many biotech products that are failing to progress through commercialization because they are still too "risky" and market returns are uncertain. These capabilities are technically advanced but novel and therefore not attractive for private capital alone. One example is mRNA technology prior to the Covid-19 pandemic. The mRNA vaccine had been under development for decades, but it only advanced to full-scale commercialization and clinical trials because of the public funding provided through Operation Warp Speed. With government support, mRNA technology was scaled up, found to be viable, and commercialized as a vaccine to protect against Covid-19. With this technology now de-risked, private industry is continuing to advance mRNA products toward other applications, such as in the treatment of cancer. The U.S. government should continue to support the commercialization and scale-up of first-in-class innovative biotech capabilities. This support will then enable the private sector to continue development for the next class of products, smoothing the pathway for new biotech applications to make it into the hands of customers.

Another area requiring government attention is the regulatory pathways for biotech products. Biotech regulatory processes in the United States are lengthy and unpredictable, affecting the ability for developers to bring new products to market. There are many government agencies with jurisdiction over some part of biotech regulation, leading to gaps, overlaps, and ambiguities. Data requirements may be outdated, or data may be difficult to obtain for new products, which can hinder or delay processes. The U.S. government should modernize its regulatory approach for biotechnology, including harmonizing efforts across agencies and developing new, simplified pathways for biotech products.

Finally, the U.S. government must continue to protect biotechnology from adversarial control and misuse. Although the technology has clear and positive civilian usages, it is evolving quickly, and policymakers should be clear-eyed about its dual-use nature and military utility. The government should continue to identify options for potential additional export control restrictions, while acknowledging that biotechnology is increasingly more distributed, accessible, and inexpensive. This can make it more difficult to identify targetable chokepoints for multilateral action, and therefore controls should be revisited periodically and reviewed for effectiveness. Allied countries will need to align their controls to make any restrictions effective.

Washington also needs to ensure that its investment screening mechanism—the Committee on Foreign Investment in the United States (CFIUS)—blocks transactions that would allow critical biotechnologies and associated data to go to adversarial entities. Biotech research and products are more likely to be stuck in early stages or strained for capital, making firms' development of those products susceptible to adversarial interest. Additionally, the U.S. government has a history of overlooking the future national security risk of biotechnology. For example, PRC biotech national champion BGI purchased the U.S. firm Complete Genomics, including its associated proprietary sequencing technology, after gaining CFIUS approval in 2013.[39] The National Counterintelligence and Security Center concluded in 2021 that the PRC's access to U.S. healthcare and genomic data poses serious privacy and national security risks.[40] However, the U.S. government still has gaps in its ability to block access to sensitive data. To address these limitations, the Department of Justice issued regulations that prevent the transfer or sale of bulk sensitive personal data, like human genomic data, to countries of concern.[41] Allied countries should consider implementing similar regimes.

The U.S. biotech sector also has critical dependencies on non-allied firms, which creates national security risks. According to a survey by the Biotechnology Innovation Organization, 79% of U.S. biotech companies contract with Chinese firms for production.[42] The U.S. Congress has considered legislation (the BIOSECURE Act) that would prohibit pharmaceutical and biotech companies from using services or equipment from Chinese "companies of concern." While the bill stalled at the end of the 118th Congress, if it does move forward again, biotech service and manufacturing firms not based in China—including South Korea's Samsung Biologics—are poised to potentially benefit from U.S. biotech companies looking for alternatives to Chinese companies.

Opportunities for International Cooperation

Maintaining leadership in biotechnology will require partnerships across U.S. and allied nations. Washington should employ several strategies to support biotechnology, both bilaterally and multilaterally. Bilateral partnerships can be the most effective means to share capabilities and infrastructure or harmonize regulatory approaches. Multilateral agreements are opportunities for focused research cooperation and shared data-collection efforts. Formal multilateral organizations are also optimal venues for promulgation of shared norms and values.

The U.S. government has recently taken steps to strengthen cooperation with partners and allies on biotechnology. The reignited Cancer Moonshot, for example, has provided an opportunity for partner nations to combine biotech and scientific resources toward a shared commitment to expand cancer treatments and care. For example, the Quad Cancer Moonshot is targeting the end

[39] Gryphon Scientific and Rhodium Group, "China's Biotechnology Development: The Role of U.S. and Other Foreign Engagement," report prepared for the U.S.-China Economic and Security Review Commission, February 14, 2019, https://www.uscc.gov/sites/default/files/Research/US-China%20Biotech%20Report.pdf.

[40] Office of the Director of National Intelligence, "China's Collection of Genomic and Other Healthcare Data from America: Risks to Privacy and U.S. Economic and National Security," February 2021, https://www.dni.gov/files/NCSC/documents/SafeguardingOurFuture/NCSC_China_Genomics_Fact_Sheet_2021revision20210203.pdf.

[41] U.S. Department of Justice, "Provisions Pertaining to Preventing Access to U.S. Sensitive Personal Data and Government-Related Data by Countries of Concern or Covered Persons," December 26, 2024, https://www.justice.gov/d9/2024-12/NSD%20104%20-%20Data%20Security%20-%201124-AA01%20-%20Final%20Rule_0.pdf.

[42] "Trade Association Survey Shows 79% of U.S. Biotech Companies Contract with Chinese Firms," Reuters, May 8, 2024, https://www.reuters.com/business/healthcare-pharmaceuticals/trade-association-survey-shows-79-us-biotech-companies-contract-with-chinese-2024-05-08.

of cancer in the Indo-Pacific.[43] These partnerships should be expanded to other strategic biotech applications, like food security and supply chain resiliency.

On biomanufacturing, the United States and its allies should prioritize establishing manufacturing hubs, advancing public-private partnerships, and incentivizing training and upskilling efforts, especially in areas of the country with talent pools that converge with biotechnology, like computer science, logistics, or shipping. The newly formed Biopharma Coalition (Bio-5), which is working to secure biopharmaceutical supply chains across the United States, the European Union, India, Japan, and the ROK, is an example of multilateralism for biomanufacturing in action.[44] The five countries will seek opportunities for their governments and the private sector to deepen coordination on policy, regulations, and R&D capabilities. Executing on this and similar partnerships can help clarify biomanufacturing supply chains within the United States and allied nations and keep the biotech industry running smoothly and securely.

There are additional areas where cross-border coordination on biotechnology will be particularly critical. First, pooling data resources and setting common standards with like-minded countries will help move forward AI applications for biotechnology. Second, regulatory harmonization can resolve potential overlaps in global regulatory pathways to clear the way for new bioproducts to enter the multinational marketplace. The United States could also coordinate market-shaping policies with allied nations interested in biotechnology, both to make the potential financial returns more attractive to private-sector companies and to keep companies moving between nations in the same sphere of interest. Finally, the United States should work with its allies to attempt to standardize technology-protection measures that stop the flow of critical biotechnologies when they could endanger national security.

The United States and allied nations will mutually benefit from cooperation in this sector, which will unlock more economic growth. To this end, Washington must redouble its efforts to engage with governments, industry leaders, and researchers across borders to maintain the leading edge for emerging biotechnology.

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43 "Launching the U.S.-ROK Next Generation Critical and Emerging Technologies Dialogue."

44 "Biden-Harris Administration's Actions to Advance American Biotechnology and Biomanufacturing," White Houe, Fact Sheet, June 25, 2024.

Policy Options to Strengthen U.S.-ROK Cooperation on Biotechnology

Hyun-Chul Kim and Michelle Rozo

Biotechnology is already widely applied in health, agriculture, energy, and industry. The convergence of AI and automation further enhances the sector's potential to drive innovation in economic, scientific, and military fields. However, these technologies also pose risks of misuse, which threaten national security and privacy, making biotechnology strategically significant in an era of global competition. The U.S. government has not yet fully prioritized biotech policy, and the lengthy and costly transition from R&D to commercialization remains a challenge. With China designating biotechnology as a strategic industry and expanding government support, continued U.S. and allied leadership is increasingly important. To sustain leadership, the United States must expand cooperation with allies like the ROK through strategic international collaboration and the establishment of normative frameworks.

The ROK is rapidly emerging as a global leader in biotechnology, contributing significantly to its economic growth and national security. The country ranks highly in research publications and patents, and Seoul hosts the world's largest clinical trial sites. Industrially, the ROK's biotech pipeline rivals that of Japan, and the country holds the world's second-largest biopharmaceutical production capacity. The biotech start-up ecosystem is thriving, with approximately 2,000 companies founded between 2017 and 2021 and venture capital investments ranking fifth globally. The ROK government has designated biotechnology as a national strategic technology to foster innovation across science and technology, economic industries, global security, public health, and the climate and environment. To achieve these goals, it is systematically enhancing support through initiatives such as the Advanced Biotechnology Initiative, the Global R&D Strategy Map for Advanced Biotechnology, and the Biomanufacturing Innovation Strategy.

The U.S.-ROK Next Generation Critical and Emerging Technologies Dialogue, established in 2023, marks a new chapter for strategic cooperation in biotechnology and innovation. Yet, despite this robust foundation, potential barriers persist. The U.S.-ROK biotech partnership is dynamic and multifaceted, but it is subject to changes in domestic politics and global conditions. Given the increasing uncertainty regarding global leadership in biotechnology, coupled with intensifying geopolitical competition, no nation can afford to pursue its goals independently. The following policy options are essential for enhancing U.S.-ROK biotech cooperation.

AI and Biotech Data Collaboration

To maximize the benefits of AI in biotechnology, the United States and the ROK should prioritize data sharing, the establishment of common standards, and the exchange of best practices for data security. Trustworthy AI, particularly in medical applications, depends on high-quality data sets. Addressing privacy and security concerns associated with sensitive data like health information requires both short-term technical solutions and long-term institutional frameworks.

Technical approaches such as federated learning, blockchain, and homomorphic encryption can prevent data breaches and facilitate tracking in case of leaks. These solutions require robust data-sharing infrastructure, including cloud systems, computing power, high-speed networks, and standardized data formats.

Institutionally, formalizing joint research into ethical, legal, and social implications and establishing bilateral data-sharing agreements are crucial. The EU-U.S. Data Privacy Framework of 2023 could serve as a model for cross-border data cooperation. Establishing AI standards and joint R&D initiatives would further enhance AI capabilities in both countries. Finally, allies should examine how to align approaches to data security. The U.S. Department of Justice's Proposed Rule Addressing National Security Risks Posed to U.S. Sensitive Data provides a model of regulations designed to block the flow of sensitive genomic data to countries of concern.

Regulatory Harmonization

Aligning global regulatory frameworks and reducing redundancies are essential to facilitate the entry of new bioproducts into international markets. Regulatory harmonization can streamline procedures, minimize duplication, and encourage innovation. Enhanced collaboration in regulatory science research, information sharing, and personnel exchanges between the U.S. FDA and the ROK Ministry of Food and Drug Safety (MFDS) is necessary.

The 2023 Memorandum of Cooperation between the FDA and MFDS on AI for medical products is a positive step. Building on this foundation, collaboration could extend to developing joint regulatory guidelines for bioproduct approval, clinical trial standards, safety evaluations, and quality controls.

A mutual recognition agreement for bioproduct safety and quality certifications could expedite approvals, reduce costs, and facilitate trade. Additionally, the United States and ROK should jointly develop ethical and safety standards for emerging biotechnologies like gene editing and synthetic biology to mitigate ethical risks and build public trust.

Market and Innovation Cooperation

Coordinating biotech policies between the United States, the ROK, and other partners can enhance product development and market access. Korean biotech firms can improve their global reach, while U.S. firms can expand their pipelines and reduce costs. The ROK ranks third globally for biotech drug pipelines, following China.

Given the reliance of U.S. multinational biopharma companies on small and medium-sized enterprises, U.S.-ROK cooperation can create complementary partnerships. The successful collaboration between Janssen and Yuhan Corporation in developing a lung cancer drug exemplifies this synergy. Building on initiatives such as the Boston-Korea Project, a large-scale U.S.-ROK collaboration on biotech R&D launched in 2024, both countries should actively expand public-private partnerships in technology development and joint workforce training programs.

For products with lower market returns, such as bio-based chemicals or biodefense products, pooling government demand through mechanisms like advanced market commitments can reduce risk and encourage private-sector innovation. Cooperation can also address security threats associated with the malicious use of biotechnology, including reviewing screening approaches for inbound investment and sharing information that could help identify and mitigate risks.

The Biomanufacturing Supply Chain

Strengthening U.S.-ROK biomanufacturing cooperation can bolster shared interests by addressing supply chain vulnerabilities. The ROK is emerging as a global biopharmaceutical manufacturing hub, with significant investments in production capacity. The Critical and Emerging Technologies Dialogue highlights successful collaboration in synthetic biology and advanced manufacturing, including a partnership between the Lawrence Berkley National Lab and the Korea Research Institute of Bioscience and Biotechnology to commercialize bioenergy, biomaterials, and bio-based chemicals.

Given the United States' reliance on overseas facilities for drug production, establishing joint biomanufacturing hubs could enhance supply chain resilience. In particular, collaboration on continuous manufacturing technology could stabilize supplies of essential medicines, such as antibiotics. Partnerships like the Bio-5 Coalition (the United States, the EU, India, Japan, and the ROK) to secure biopharmaceutical supply chains can be expanded and strengthened through joint actions.

Health Equity and Global Health Cooperation

Expanding biobank data sharing between the United States and ROK can improve understanding across diverse populations and promote global health equity. Addressing biases in AI data sets is essential for developing inclusive medical innovations. This approach aligns with U.S. and ROK health policy goals and would benefit diverse populations.

Collaborative efforts on treatments for neglected tropical diseases, vaccines, and affordable medical devices can improve global health outcomes and reduce costs through economies of scale. The ROK could join initiatives like the Quad Cancer Moonshot or lead new multinational efforts to overcome dementia and other conditions that have no effective treatment. Strengthening public-private partnerships and shared research platforms between the United States and South Korea will support these initiatives.

Delays or the lack of decisive action in advancing strategic biotech collaboration between the United States and its allies such as South Korea risks replicating challenges seen in other advanced technology domains, such as semiconductors and AI, where significant investments and trade measures were required to regain competitive advantages. Furthermore, as demonstrated during the Covid-19 pandemic, insufficient coordination could exacerbate vulnerabilities in health security, including shortages of critical medical supplies, ultimately undermining diplomatic leverage against China. In the face of intensifying U.S.-China competition, strategic biotech collaboration between the United States and South Korea is imperative to maintain leadership, drive innovation, and enhance global health security while addressing shared challenges and shaping global standards.

U.S.-ROK Collaboration to Advance Quantum Technology and Industry

Jae Young Kwon and Hodan Omaar

EXECUTIVE SUMMARY

This chapter analyzes the efforts of the U.S. and the Republic of Korea (ROK) to support quantum technology development and related ecosystems and proposes pathways to promote cooperation on advancing quantum technology with shared values.

MAIN ARGUMENT

In the first section, Jae Young Kwon introduces South Korea's efforts to foster quantum technology, including policies, investment, and legislation, and also examines the country's ecosystem for developing quantum technology. The early development stage and the interdisciplinary nature of quantum technology provide opportunities for cooperation to advance innovation. However, as quantum technology is expected to be critical for national security, international cooperation should be carried out strategically. Given the long history of cooperation between the U.S. and South Korea in various sectors, including defense as well as science and technology, U.S.-ROK cooperation in quantum technology will play an important role in advancing innovation and also strengthening national security. In the second section, Hodan Omaar examines the strengths and blind spots in U.S. leadership in quantum technology. Decades of investment and world-class research have put the U.S. at the forefront, particularly in quantum computing, but a fragmented approach and limited focus on sensing and communication create strategic gaps. While private-sector funding remains strong, recent declines highlight the risks of an uncoordinated strategy. Collaboration with the ROK could help strengthen supply chains, accelerate commercialization, and bolster U.S. leadership in an increasingly competitive global landscape.

POLICY IMPLICATIONS

- Quantum technology is one of the most promising future technologies for both achieving economic prosperity and strengthening national security and will therefore have a significant impact on global competition.
- Cooperation between like-minded countries is critical for securing leadership in quantum technology. With the U.S.-ROK partnership as a foundation, cooperation in R&D and workforce exchange will contribute to advancing quantum technology more rapidly.
- Multilateral and bilateral cooperation will be critical for developing a healthy global quantum ecosystem. Increased U.S. and ROK cooperation with other like-minded countries can make export controls and international standards and regulations more effective.

Emerging quantum technologies have the potential to achieve dramatic economic and security impacts through advances in computing, sensing, and communication. During an era of heightened geostrategic and technological competition, leadership in quantum technology could alter global power dynamics. As such, it is essential that the United States, the Republic of Korea (ROK), and other like-minded partners work together to ensure that they are at the forefront of developments in this domain.

This chapter begins with an overview by Jae Young Kwon of South Korea's quantum ecosystem and related development policies and strategies. Hodan Omaar then examines the strengths, gaps, and challenges in the United States' development of quantum technology. The chapter concludes with the authors jointly assessing the policy options for the United States and South Korea to increase their collaboration in ways that could advance each country's quantum goals.

South Korea's Foundation for the Development of Quantum Technology and the Need for U.S.-ROK Cooperation[1]

Jae Young Kwon

When Google demonstrated quantum supremacy with its self-produced quantum processor Sycamore in 2019,[2] the world started to recognize that quantum computing was no longer a research topic among scientists but had become a technology with great capabilities and real-world applications. However, it took only two years for a team of scientists in China to claim they had developed a light-based quantum computer that could perform some calculations at speeds 10 billion times as fast as Google's Sycamore processor.[3] While the global scientific community regarded this claim with some suspicion, China's announcement nonetheless surprised the world and initiated the race for leadership in quantum technology.

Quantum technology is generally divided into three categories—quantum computers, quantum communication, and quantum sensors—with each promising to revolutionize various industries. Quantum computers, which are the most disruptive technology among the three categories, are capable of performing certain types of calculations significantly faster than classical computers. This is largely due to quantum computing's use of "qubits." Unlike a bit in classical computing, which can represent a single binary state such as 1 or 0, a quantum bit (or qubit) can exist in superposition of 0 and 1, thereby also representing all the possible states between 0 and 1. The superposition characteristic of a qubit enables quantum computers to be in multiple states simultaneously, and the number of possible states grows exponentially as the number of qubits increases. Due to the unique properties of qubits, a quantum computer can conduct more with qubits than a classical computer does with an equal number of bits, allowing it to conduct complex, probabilistic computing. Theoretically, a quantum computer that can manipulate millions of qubits has the ability to break existing encryption systems built on classical computation.

Quantum communication—and particularly quantum key distribution—utilizes individual photons as information carriers rather than using classical electromagnetic waves. This approach

1 This section is authored by **Jae Young Kwon**, who is an associate research fellow at the Korea Institute of Science and Technology Evaluation and Planning (KISTEP). The views expressed are those of the author and do not represent the official opinion of KISTEP.

2 Frank Arute et al., "Quantum Supremacy Using a Programmable Superconducting Processor," *Nature*, no. 574 (2019): 505–10.

3 Han-Sen Zhong et al., "Quantum Computational Advantage Using Photons," *Science* 370, no. 6523 (2020): 1460–63.

can facilitate stronger network system security. As quantum decryption capabilities advance, it will become critically important to develop quantum communication technology that is able to provide new means of secure transmission for sensitive information. Quantum sensors refer to a broad range of technologies that measure variables such as gravity, acceleration, electric fields, and magnetic fields with enhanced precision. Quantum technology is more than just an upgrade of current information technologies; it holds the potential to change the paradigm of conventional industry and facilitate innovation in various sectors, including finance, chemical research, and artificial intelligence. For example, quantum technologies can optimize existing industries such as the pharmaceutical industry through quantum modeling of molecular structures and create new approaches to industries such as cryptography and cybersecurity.[4] The economic value of quantum computing is largest among quantum applications, which are expected to create 250,000 new jobs by 2030 and $1 trillion in value by 2035.[5]

Yet while quantum technology will likely create significant new economic opportunities, it also has the potential to bring about significant national security challenges, including through its utilization for military purposes.[6] Quantum technology is thus expected to be a key national security technology in the future. However, the technology is still at an early stage. Although some applications have almost reached the level of commercialization, there exist many technological challenges that need to be addressed through extensive research and development. Some experts claim that we might have to wait ten to thirteen years for quantum computers to demonstrate practical commercial applications.[7]

South Korea has been slow in fully supporting quantum technology, which was not a priority for the country until IBM and Google unveiled their quantum computers in 2019. Since then, South Korea's view of quantum technology has changed dramatically. After selecting quantum technology as one of twelve national strategic technologies in 2022, the ROK government and policymakers are actively building national plans and strategies aimed at fostering the development of quantum technology.[8] Quantum is now regarded as second to only advanced semiconductors—an industry that South Korea has led globally for decades.[9] The country's efforts to develop its semiconductor industry have resulted in world-class fabrication facilities, advanced processing technology, and a highly educated workforce, all of which can now be applied as strategic advantages in developing quantum processors.

Recent South Korean Policies to Support Quantum Technology

South Korea released multiple policy packages in 2023–24 that demonstrate its emphasis on financial and institutional support for building a quantum ecosystem and achieving a world-class level of investment in quantum R&D. This included legislation designed to ensure long-term governmental support for the development and application of quantum computing, communication, and sensing technologies. These efforts have laid the groundwork for the development of quantum technology in South Korea, albeit with a late start.

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4 "How Can Quantum Technologies Drive Economic Security and Growth?" Quantum Innovation Summit, July 29, 2024.

5 "The Quantum Insider Projects $1 Trillion in Economic Impact from Quantum Computing by 2035," Quantum Insider, September 2024.

6 Michal Krelina, "Quantum Technology for Military Applications," *EPJ Quantum Technology* 8, no. 24 (2021).

7 McKinsey and Company, "What Is Quantum Computing?" May 2023.

8 Ministry of Science and ICT of the Republic of Korea (ROK), *National Strategic Technology Nurture Plan* (Seoul, 2022).

9 Ministry of Science and ICT (ROK), *National Quantum Strategy* (Seoul, 2023).

South Korea's endeavor to foster quantum technology is well illustrated in its National Quantum Strategy (NQS), which was announced in June 2023 by the Ministry of Science and ICT and covers ten years of policies for supporting quantum development until 2035.[10] According to the NQS, South Korea plans to invest $2.3 billion with the goal of becoming the global center of the quantum economy by 2035. This would make it one of the five largest investors in quantum technology.[11] The NQS prioritizes the development of a quantum workforce, with plans to train 2,500 core researchers by 2035, which is seven times the current level. South Korea has also established numerous long-term goals for each of the three main applications of quantum technology (computing, communication, and sensing): building a 1,000-qubit general-purpose quantum computer based on a superconducting approach (which is distinct from the photonic, or light-based, approach taken by Chinese engineers in 2020) by the early 2030s with homegrown core technologies; developing core quantum communication technologies such as quantum memory and quantum repeaters to realize communication networks capable of transmitting long-distance signals of 100 kilometers or more; and developing high-precision navigation technologies using ultra-sensitive gravitometers and magnetometers based on quantum-sensing technology for advanced industry and defense that are not reliant on GPS, which is vulnerable to electromagnetic interference and jamming.

In addition to presenting a roadmap of quantum milestones, the Ministry of Science and ICT proposed a set of comprehensive policies to support the development of dedicated quantum fabrication facilities (where quantum devices like quantum processors are made), quantum foundries (research labs where design, integration, and application development take place), and plans for fostering quantum start-ups. Strengthening international cooperation with like-minded partners such as the United States, the European Union, and Japan is also a critical part of the NQS. South Korea plans to increase government funding for international cooperation via the promotion of international joint R&D and workforce exchanges.

In October 2023, as a follow-up to the NQS, South Korea passed the Act on the Promotion of Quantum Science Technology and the Quantum Industry (the Quantum Law),[12] which is aimed at providing legal support for implementing many of the strategies demonstrated in the NQS. The legislation also encompasses a variety of activities that the government will support, including construction of a national governance system of quantum research, establishment of research hubs and clusters, commercialization of research outcomes, and promotion of international cooperation. The enactment of the Quantum Law is driven by a bipartisan consensus that quantum technology will play an important role in South Korea's economy and security, and the legislation is expected to guarantee stable government support for quantum technology.

In April 2024, quantum technology was selected as one of South Korea's three "game-changer" technologies—along with AI-relevant semiconductors and advanced biotechnology—that should be prioritized in terms of R&D.[13] According to the Presidential Advisory Council on Science and Technology, which is the top decision-making body in the field of science and technology, South Korea seeks to become one of the top three countries globally in all three technologies by 2030.

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10 Ministry of Science and ICT (ROK), *National Quantum Strategy*.

11 McKinsey and Company, "Quantum Technology Monitor," April 2024.

12 "The 'Act on the Promotion of Quantum Science and Technology and the Quantum Industry' Passed the National Assembly," *Korean Lawtimes*, October 19, 2023, https://www.lawtimes.co.kr/LawFirm-NewsLetter/192285.

13 Ministry of Science and ICT (ROK), "Three Major Game Changer Technology Initiatives," 2024.

To achieve this, the government has launched new initiatives for each of the game-changer technologies. Under the Quantum Initiative, nine priority technologies to strategically prepare for the quantum era were identified: (1) quantum processors, (2) quantum algorithms and software, (3) quantum networks, (4) quantum sensing, (5) quantum materials, components, and equipment, (6) quantum device and process technologies, (7) digital-quantum hybrid technology, (8) quantum killer applications, and (9) quantum artificial intelligence. The ROK government plans not only to make intensive investments in the R&D of the game-changer technologies but also to advance the value chain of each technology to open new market opportunities and strengthen strategic cooperation with allies.

South Korea's Quantum Ecosystem and Outcomes

While there is a diverse array of stakeholders actively involved in quantum R&D in South Korea, and the number of established and start-up companies in the quantum ecosystem is increasing, the development of quantum technology in South Korea is led by national research institutes and universities. The Korea Research Institute of Standards and Science (KRISS) is one of the leaders in quantum-computing and quantum-sensing research in several hardware modalities, including superconducting circuits for generating qubits. The Korea Institute of Science and Technology (KIST), which is South Korea's first national research institute, has a huge group that conducts research in quantum computing, quantum communication, and quantum sensing based on modalities like photonic qubits and diamond nitrogen-vacancy center qubits.[14] Other national institutes such as the Electronics and Telecommunication Research Institute (ETRI) and the Korea Institute of Science and Technology Information (KISTI) are developing quantum software and cloud-service technologies, in addition to quantum hardware technologies. Several universities are playing key roles as well and have established quantum research centers and laboratories. For example, Yonsei University's Institute for Quantum Information Technology and Sungkyunkwan University's Quantum Information Research Support Center were established to contribute to the creation of South Korea's quantum ecosystem through education, research, and global networking.[15]

In the private sector, major ROK corporations such as KT Corporation, SK Telecom, and LG Uplus are developing technologies in quantum communication, particularly by developing essential hardware components for both quantum key distribution and post-quantum cryptography. South Korea is especially well positioned for a quantum transition, as it already has world-class optical-fiber infrastructure, a tech-savvy labor pool, and the technological foundation necessary for the introduction of quantum technologies. LG Electronics and POSCO Holdings are collaborating with various global companies outside South Korea to develop and make use cases for quantum computers, such as applications of new material designs. Additionally, start-ups such as First Quantum and Qunova Computing are providing software solutions for quantum computing and thereby contributing to the discovery of applications for quantum computers. The number of start-ups involved in quantum technology is on the rise. In order to vitalize South

[14] Photonic qubits refer to an approach that deploys a photonic circuit to use a single photon as a qubit. Diamond nitrogen-vacancy center qubits refer to an approach that uses defects, formed when a nitrogen atom substitutes for a carbon atom adjacent to a vacancy in a diamond lattice, which creates unique spin properties that allow for manipulation through microwave and magnetic field variation.

[15] James Dargan, "A Brief Overview of Quantum Computing in South Korea in 2023," Quantum Insider, July 28, 2023.

Korea's quantum industrial ecosystem, the Korea Quantum Industry Association was founded in 2022 and has more than 70 members as of 2024.

Some major actors in South Korea's quantum ecosystem have achieved remarkable results, positioning the country as an emerging global leader in quantum technology. In January 2024, KRISS reported the successful development of a 20-qubit superconducting quantum computer.[16] It is currently in the process of building a 50-qubit superconducting quantum computer aiming to operate with cloud service by 2026. Although KRISS is leading this project, other national institutions like KISTI are participating to incorporate software and cloud-service technologies. ETRI has recently announced that it developed a photonic circuit chip that creates 8 qubits.[17] Photonic qubits also make possible a promising approach for building a quantum computer as they have advantages such as scalability and operation temperature. With the developed photonic chips, scientists plan to research various quantum phenomena, such as multiple entanglement of qubits generated from photons, and will finally be able to build a scaled-up photonic qubit quantum computer. ETRI has been conducting extensive research in quantum photonic chips and their application to quantum communication as well as quantum computers. For over a decade, ETRI, KIST, and several major South Korean telecommunication companies like SK Telecom and KT have been collaborating to commercialize quantum key distribution. As a result, South Korea has secured numerous international standards in the field of quantum communication that have been adopted by the European Telecommunications Standards Institute and the International Telecommunication Union.[18]

South Korea has also emphasized international cooperation, including with the United States, to advance its quantum ecosystem. In April 2023 the United States and South Korea signed a joint statement on cooperation in quantum information science and technology.[19] In addition to national-level cooperation, there has been significant global R&D collaboration between researchers. Yonsei University and Sungkyunkwan University have partnered with IBM to access its quantum computing through cloud service. Yonsei University is also working with IBM to deploy a 127-qubit processor, which would be the world's third onsite deployment of a full quantum system for IBM.[20] Seoul National University signed a memorandum of understanding with IonQ to promote R&D collaboration and implement a joint educational program.[21] Universities in South Korea and the United States are also jointly designing workforce exchange and education programs. For example, the Korea Advanced Institute of Science and Technology partnered with MIT and held the Quantum Information Winter School for nurturing quantum talents in January 2024.[22] Collaboration between the U.S. national labs and South Korea's national research institutes for quantum research is underway. KRISS and the U.S. National Institute of Standards and Technology have been engaged in collaboration since 1994, and the two organizations have

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16 "KRISS Launches 'Quantum Computing MPE Scale-Up Valley Consortium,'" Korea Research Institute of Standards and Science, July 8, 2024.

17 "Quantum Computing Researchers Develop an 8-Photon Qubit Chip," National Research Council of Science and Technology, November 14, 2024.

18 "Korea's Quantum Cryptography Communication-Related Projects Going Well," *Business Korea*, January. 28,2022.

19 "The United States and Republic of Korea Sign Joint Statement to Boost Quantum Cooperation," National Quantum Initiative, April 26, 2023, https://www.quantum.gov/the-united-states-and-republic-of-korea-sign-joint-statement-to-boost-quantum-cooperation.

20 Hanhee Paik and Kyungsun Moon, "Yonsei University and IBM Quantum Are Building Korea's Quantum Ecosystem," IBM, Quantum Computing Blog, March 14, 2023.

21 "IonQ and Seoul National University's Center for Quantum Information Science Education (CQISE) Enter Agreement to Support Quantum Workforce Development," IonQ, February 9, 2024.

22 Kyung Ju Kang, "KAIST, MIT Jointly Open Quantum Winter School," *Korea Economic Daily* (global edition), January 8, 2024.

decided to expand the scope of collaboration to superconducting quantum-computing research.[23] The U.S. Air Force Office of Scientific Research also has a long-standing quantum technology collaboration with the Ministry of Science and ICT of South Korea.

The Global Landscape and China's Rapid Growth

The efforts to secure proprietary quantum technologies are global. Many countries such as the United States, Japan, the UK, Australia, and South Korea are investing in quantum R&D and releasing their own national strategies to develop their competitiveness in this field. More than twenty EU members have stated commitments to cooperate on quantum technologies to make Europe the global center of quantum.[24] Considering various aspects that determine the leadership of quantum technology, such as the source of technology, its quality, and the industrial ecosystem, the United States is currently the most advanced country in the world in quantum capabilities. However, China is catching up rapidly, presenting high-quality research outputs in every application of quantum technology. China is also believed to have technologically surpassed the United States in the field of quantum communication, though this is largely due to the U.S. government's strategic decision to prioritize post-quantum cryptography over quantum key distribution networks.[25]

China's rapid growth in quantum technology is raising concerns not only in the United States but in many other countries, as Beijing is seeking to deploy quantum technologies to improve Chinese military capabilities.[26] In order to counter China's rapid advancements in quantum technology and prevent the transfer of technology to China, the U.S. government has implemented export controls on the sale of quantum computers, related equipment, components, software, and technology to China since 2021. In addition, the U.S. government announced new regulations in 2024 to restrict U.S. investments in China's quantum technology sector.[27] But this goal of maintaining a significant technological gap with China cannot be achieved by the United States alone. In particular, technology and export controls can only be effective if the United States works with other countries that play major roles in supply chains. As a result, international cooperation in quantum technology is becoming more important but also more complex. In this regard, the United States initiated an international dialogue called "Pursuing Quantum Information Together: 2N vs. 2N," which started in 2022 with twelve countries that share its values. This dialogue seeks to strengthen solidarity among members, share best practices and resources, promote collaboration and workforce exchanges, and discuss regulations and norms to protect technology. In 2023, South Korea joined the dialogue as the thirteenth member as part of its efforts to actively cooperate with major players in quantum technology.

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23 "Strengthening Cooperation in Quantum Technology between KRISS and NIST," KRISS, January 31, 2024.

24 "European Declaration on Quantum Technologies," European Commission, December 6, 2023, https://digital-strategy.ec.europa.eu/en/library/european-declaration-quantum-technologies.

25 Edward Parker, "Promoting Strong International Collaboration in Quantum Technology Research and Development," RAND Corporation, February 2023.

26 Jeanne Whalen, "China's Top Quantum Scientist Has Ties to the Country's Defense Companies," *Washington Post*, December 26, 2019, https://www.washingtonpost.com/technology/2019/12/26/chinas-top-quantum-scientist-has-ties-countrys-defense-companies.

27 "Department of Commerce Implements Controls on Quantum Computing and Other Advanced Technologies Alongside International Partners," U.S. Department of Commerce, September 5, 2024.

Conclusion

The interdisciplinary nature of quantum technology means that international cooperation is essential to accelerate innovation in the early stage of development. Moreover, strategic cooperation among allies and like-minded countries is essential, as the world is facing unprecedented competition over technological development. South Korea and the United States have a long history of cooperation in areas such as defense, science and technology, and economics. Given South Korea's strength and potential, cooperation in quantum technology between the two countries is expected to be mutually beneficial.

South Korea's skilled workforce, advanced manufacturing capabilities and fabrication technology, technological infrastructure, and strong government support for the development of quantum technology position it well to become a global leader. But in order to advance the quantum industry, South Korea and the United States will need to expand their cooperation, most notably by strengthening collaboration on R&D. Additionally, multilateral cooperation in areas such as international standards, export controls, and supply chain resilience should be prioritized. Strategic cooperation between South Korea and the United States is expected to pave the way for advancing quantum technology and safeguarding the national security of both countries.

How the United States Drives Quantum Innovation—and Where It Needs ROK Collaboration[28]

Hodan Omaar

An Overarching Approach to Quantum Innovation

While the foundations of quantum theory were laid by European pioneers like Max Planck, Albert Einstein, Niels Bohr, Werner Heisenberg, and Erwin Schrödinger at the beginning of the twentieth century, the United States quickly became a global leader in advancing quantum science throughout the latter half of the century. U.S. universities—including MIT, Harvard, and Stanford—became key hubs for quantum research, making both theoretical and experimental progress. This leadership was supported by substantial government investment through agencies like the Department of Energy and the National Science Foundation, ensuring that universities had the financial backing to pursue ambitious quantum research projects.

In the United States, as around the world, the cutting edge of quantum technology in recent years has shifted from academic and research institutions toward private industry. Companies like IBM, Google, and Honeywell not only have been involved in foundational research but also have demonstrated quantum hardware prototypes, especially in quantum computing. U.S. industry benefits from its expertise in areas like semiconductors, lithography, and chip manufacturing—essential building blocks for quantum hardware. Collaborations between major companies and U.S. research labs have further driven advancements in quantum technologies, reinforcing the country's capacity to scale quantum innovations from the lab to real-world applications.

Despite these strengths, the U.S. quantum ecosystem faces challenges as other countries rapidly expand their quantum capabilities. The global quantum technology market is divided into three main areas: computing, communication, and sensing. Among these, quantum computing holds the largest economic potential and is projected to account for 87% of the market by 2040.[29] However, it is also the least mature, requiring significant breakthroughs to achieve its transformative promise for industries like pharmaceuticals and finance. In contrast, quantum communication and sensing, while representing smaller portions of the market—7% and 6%, respectively—are much closer to practical applications, offering near-term benefits such as secure data transmission and precision navigation.[30] The United States has primarily focused on quantum computing, evidenced by major investments from companies like IBM, Google, and Microsoft, alongside significant federal funding through the Department of Energy for next-generation superconducting qubits. However, this focus has often come at the expense of pursuing nearer-term opportunities in quantum communication and sensing. In contrast, China has prioritized these more market-ready technologies, leveraging centralized ecosystems like Hefei's Quantum Avenue to rapidly commercialize innovations.[31] This approach has allowed China to lead in areas such as secure

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[28] This section is authored by **Hodan Omaar**, who is a senior policy manager focusing on AI policy at the Information Technology and Innovation Foundation's Center for Data Innovation.

[29] McKinsey and Company, "Quantum Technology Monitor 2023," April 2023, https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20technology%20sees%20record%20investments%20progress%20on%20talent%20gap/quantum-technology-monitor-april-2023.pdf.

[30] Ibid.

[31] Hodan Omaar and Martin Makaryan, "How Innovative Is China in Quantum?" Information Technology and Innovation Foundation, September 2024, https://itif.org/publications/2024/09/09/how-innovative-is-china-in-quantum.

quantum communication. Without a more balanced strategy, the United States risks ceding early economic and strategic gains to countries that are capitalizing on these immediate opportunities.

One of the key characteristics of the U.S. approach is its diverse and decentralized funding landscape. While a broad range of government departments and private investments fund quantum research, this fragmented approach can create inefficiencies and lack strategic coordination. Without a unified, centrally directed strategy, various research efforts sometimes progress in parallel, which risks diluting the overall impact and slowing momentum. This lack of coordination across institutions, universities, and companies has led some experts to call for a more coherent, streamlined direction for U.S. quantum innovation.

At the same time, collaboration on the international stage has been under-leveraged. Although the United States has established bilateral agreements recognizing the importance of international partnerships in quantum research, there remains room for deeper and more sustained joint R&D efforts with key allies. This is where the ROK presents a significant opportunity for cooperation.

The U.S. Quantum Industry

The U.S. quantum technology industrial base leads the world in size and diversity. While some countries' industrial bases focus more on investments from large publicly owned conglomerates or midsized private firms, the U.S. industrial base encompasses a mix of established tech giants and a growing number of innovative start-ups. As of 2020, approximately 182 firms were identified within this rapidly evolving sector. Leading companies like IBM, Google, Honeywell, and Microsoft are at the forefront of quantum computing, investing heavily in the development of hardware, algorithms, and software platforms, while start-ups contribute agility and specialized expertise, driving innovation and competition within the industry. Many of the most successful U.S. quantum start-ups today are university offshoots that were able to make use of university research facilities and skills for their commercial needs. For example, IonQ emerged from a collaboration between the University of Maryland and Duke University, and Zapata Computing came from Harvard.[32]

Private-sector investment in quantum technology in the United States far surpasses other countries. U.S. quantum start-ups represent around 25% of global quantum start-ups by number of firms and small and medium-sized enterprises, and they have attracted around $1.28 billion in venture capital as of 2022.[33] By comparison, the European Union, with a similar proportion of start-ups, has secured ten times less investment.[34] This dominant investment position reflects both the availability of capital and an investor culture willing to take calculated risks to drive innovation.

However, private-sector investment in U.S. quantum technologies has seen significant fluctuations in recent years. After peaking at $2.4 billion in 2021, investment levels declined sharply to $1.1 billion in 2024 (a 54% decrease).[35] This steep reduction mirrors broader economic

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[32] Hodan Omaar, "The Case for a National Quantum Computing Research Task Force in the United States," Center for Data Innovation, June 2021, https://datainnovation.org/2021/06/the-case-for-a-national-quantum-computing-research-task-force-in-the-united-states.

[33] Edward Parker et al., *An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology* (Santa Monica: RAND Corporation, 2022), https://www.rand.org/pubs/research_reports/RRA869-1.html.

[34] European Quantum Flagship, "Strategic Research and Industry Agenda 2030," February 2024, https://qt.eu/media/pdf/Strategic-Reseach-and-Industry-Agenda-2030.pdf.

[35] Hideki Tomoshige, "Innovation Lightbulb: Private Investment in Quantum Technology," Center for Strategic and International Studies, June 14, 2024, https://www.csis.org/analysis/innovation-lightbulb-private-investment-quantum-technology.

trends, including market adjustments, geopolitical risks, and shifts in investment strategies that have made investors more cautious.

The United States has established a problem-focused, industry-led consortium called the Quantum Economic Development Consortium (QED-C), whose primary goal is to cultivate the quantum industry. With more than two hundred members, QED-C brings industry together to identify high-impact applications of quantum technologies as well as any gaps in the enabling technologies, standards, and workforce needed to realize those applications. The United States is not alone in creating such a body. South Korea established the Quantum Industry Association in November 2022, and other countries and regions have similar consortiums, such as Japan's Quantum STrategic Industry Alliance for Revolution, the Quantum Industry Canada, and the European Quantum Industry Consortium. All are doing similar and important work, but QED-C has been critical for the United States in two particular areas: identifying supply chain dependencies and supporting industrial commercialization.

U.S. Public-Sector Support for Quantum R&D

Both the executive and legislative branches have taken substantial steps in recent years to shape the nation's quantum information science (QIS) policy. From the executive side, the White House has played a key role in establishing a national strategy for quantum technologies. The National Science and Technology Council, which oversees the coordination of quantum policy across the federal R&D system, has published two landmark reports. The first, released in 2016 during the Obama administration and titled "Advancing Quantum Information Science: National Challenges and Opportunities," emphasized three guiding principles: maintaining steady and adaptable core programs, investing strategically in time-bound projects, and actively monitoring advancements to adapt policy in response to breakthroughs.[36] In 2018, during the Trump administration, the National Science and Technology Council followed with a second report, titled "National Strategic Overview for Quantum Information Science."[37] This report outlined six major priorities for federal investment in quantum research: adopting a science-first approach, building a quantum-smart workforce, enhancing engagement with the private sector, providing the necessary infrastructure, ensuring both national security and economic competitiveness, and advancing international collaboration in the quantum field.

On the legislative front, the passage of the National Quantum Initiative Act (NQIA) in December 2018 marked a significant legislative achievement for quantum R&D. The NQIA provided a formal framework for advancing quantum research, authorizing more than $1.2 billion in funding over five years (2019–23). Key agencies like the National Institute of Standards and Technology, National Science Foundation, and Department of Energy were tasked with implementing various quantum initiatives. The legislation also established the National Quantum Coordination Office to synchronize efforts across government, academia, and industry and created the National Quantum Initiative Advisory Committee to provide expert guidance on national quantum programs.

[36] National Science and Technology Council, "Advancing Quantum Information Science: National Challenges and Opportunities," July 2016, https://obamawhitehouse.archives.gov/sites/default/files/quantum_info_sci_report_2016_07_22_final.pdf.

[37] National Science and Technology Council, "National Strategic Overview for Quantum Information Science," September 2018, https://www.quantum.gov/wp-content/uploads/2020/10/2018_NSTC_National_Strategic_Overview_QIS.pdf.

Further support for quantum R&D came with the passage of the CHIPS and Science Act of 2022. The legislation targeted advancements in quantum networking infrastructure, tasked the National Institute of Standards and Technology with developing quantum communication standards, and established Department of Energy programs to enhance access to quantum-computing resources for researchers. Beyond research, the CHIPS Act initiated a transformative effort to establish regional tech hubs, aimed at supercharging quantum innovation across the United States. One notable example is the designation of the Chicago region as an official tech hub for quantum technologies by the Biden administration.[38]

Unfortunately, political momentum to advance quantum information science stalled in 2024. The NQIA expired in September 2023, and Congress delayed reauthorizing a second iteration of the legislation for over a year. This delay stemmed largely from competing legislative priorities, with the regulation of artificial intelligence dominating the tech policy agenda. While there was bipartisan agreement on the importance of quantum technologies, staffers noted that resources and political attention were concentrated elsewhere.

In December 2024, however, the Senate introduced the National Quantum Initiative Reauthorization Act to revive and expand the original program.[39] The new legislation significantly increases funding, authorizing $2.7 billion for 2025–29—more than doubling the funding levels of the original NQIA. The bill also shifts the focus from basic research to applied quantum technologies, emphasizing commercialization and practical uses. Among its updates, the new law establishes three new quantum research centers at the National Institute of Standards and Technology, five multidisciplinary quantum research and education centers at the National Science Foundation, and a new quantum workforce hub. It also supports enhanced quantum test beds and expands the scope of the initiative to include additional agencies, such as the National Institutes of Health, State Department, and Small Business Administration. Additionally, NASA's quantum-sensing and satellite projects for earth science receive dedicated support under the reauthorization.

This legislation marks an important step forward, signaling renewed congressional commitment to sustaining and broadening the nation's leadership in quantum technologies. The inclusion of dedicated support for quantum sensing reflects a clear acknowledgment of near-term priorities, including countering China's advancements in these critical areas of innovation. Looking ahead, strong bipartisan support for quantum R&D suggests continuity in U.S. policy regardless of the new administration's priorities. Both the Trump and Biden administrations have emphasized quantum technology as critical to maintaining economic competitiveness and countering China—a consensus that is likely to guide future policymaking.

International Collaboration

The United States has signed several cooperative bilateral agreements to facilitate closer collaboration with like-minded partners, including with the ROK on April 25, 2023. Cooperating with like-minded countries on developing QIS technologies is crucial because of the expense, complexity, and scale required to innovate and manufacture necessary associated materials. U.S. policymakers have recognized that in the face of competition and challenges from China,

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[38] Becky Beaupre Gillespie, "Chicago Region Designated U.S. Tech Hub for Quantum Technologies by Biden-Harris Administration," University of Chicago News, October 23, 2023, https://news.uchicago.edu/story/chicago-region-designated-us-tech-hub-quantum-technologies-biden-harris-administration.

[39] John Russell, "National Quantum Initiative Act Reauthorization Bill Calls for $2.7B and New Centers," HPCwire, December 4, 2024, https://www.hpcwire.com/2024/12/04/national-quantum-initiative-act-reauthorization-bill-calls-for-2-7b-and-new-centers.

allied cooperation is critical. The State Department and the National Quantum Coordination Office play key roles in facilitating international engagements. In addition to bilateral agreements, different agencies, each with its own mission and authority, have various mechanisms to support collaboration, such as funding joint research, facilitating international student programs, and allowing visiting researchers access to U.S. facilities. For example, the National Science Foundation funds collaborative international QIS projects with partner organizations, and the Department of Energy engages international institutions through partnerships with its national laboratories and research centers.

However, the United States struggles to capitalize on the international agreements it has signed due to insufficient funding. The National Quantum Initiative Advisory Committee, which advises the government on quantum science and technology, highlighted this issue in a June 2023 report, stating that "for these statements to yield results, these international collaborative research initiatives need to be funded and coordinated by the appropriate U.S. agencies."[40] This lack of financial support hampers the execution of established agreements and limits the effectiveness of collaborative efforts.

Moreover, the fragmented nature of the U.S. approach complicates international collaboration. Often a single country will engage multiple U.S. agencies separately to propose partnerships, leading to gaps in awareness among agency personnel. This decentralized approach hinders the government's ability to participate in large-scale multinational partnerships. For instance, the Eureka initiative, launched by the EU to support collaborative research in applied quantum technologies, successfully garnered involvement from sixteen countries, including the ROK.[41] The United States, however, was unable to engage with this initiative due to a lack of established interagency coordination.

The United States has also actively engaged in quantum technology collaboration through minilateral security frameworks. One such initiative is the Quad Investors Network, associated with the Quad partnership comprising the United States, Japan, India, and Australia. The initiative aims to enhance cooperation in critical and emerging technologies, including quantum information science, by bringing together investors, academics, and industry leaders from member nations to drive innovation and promote cross-border investments. In July 2024 the network's Quantum Center of Excellence published a comprehensive report that outlines the quantum capabilities of the Quad nations and identifies strategic opportunities within the quantum technology value chain.[42] While this report serves as a foundational blueprint for fostering cross-border investments and technological cooperation, tangible outcomes such as joint research projects and significant cross-border investments have yet to materialize.

Supply chain dependencies. U.S. allies provide various key components in the quantum technology supply chain. In some instances, the United States is reliant on its allies for these components. For example, Finland and the United Kingdom are leaders in the development and production of cryogenic devices, which are indispensable for creating the extremely cold conditions

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40 National Quantum Initiative Advisory Committee, "Renewing the National Quantum Initiative: Recommendations for Sustaining American Leadership in Quantum Information Science," Report, June 2023, https://www.quantum.gov/wp-content/uploads/2023/06/NQIAC-Report-Renewing-the-National-Quantum-Initiative.pdf.

41 "Call for Proposals on Applied Quantum Technologies," Eureka Network, December 9, 2024, https://eurekanetwork.org/opencalls/network-projects-quantum-call-2024.

42 "QUIN Quantum Center of Excellence Releases Its Expert Task Force Report on Opportunities in the Quantum Technologies Value Chain across the Quad Nations," Quad Investors Network, July 31, 2024, https://quadinvestorsnetwork.org/news/quin-quantum-center-of-excellence-releases-its-expert-task-force-report-on-opportunities-in-the-quantum-technologies-value-chain-across-the-quad-nations.

needed for certain quantum computers to operate. In other instances, however, the United States is reliant on adversaries. China, for example, dominates the market for rare earth ions, which constitute one of the most versatile materials for building QIS technologies. Rare earth ions can maintain their quantum states for relatively long periods of time and emit and absorb light at very specific wavelengths, making them useful for applications such as quantum communication, quantum sensing, and quantum computing. Today, China accounts for 63% of the world's rare earth mining, 85% of rare earth processing, and 92% of rare earth magnet production.[43]

Export controls. One potential challenge for international collaboration is export controls. In the United States, the Department of Commerce's Bureau of Industry and Security regulates the export of sensitive technologies, including those related to quantum technology, under the Export Administration Regulations. In September 2024, it imposed export controls targeting quantum-computing and advanced semiconductor technologies, aimed at preventing these technologies from being diverted for military use by rival nations. The rule mandates licensing for exports of specific high-tech goods, such as quantum-computing equipment and related chipmaking technologies. For South Korea, which heavily depends on high-tech exports, the impact of these controls is fortunately expected to be limited. As the ROK Ministry of Trade, Industry and Energy itself has noted in response to the new rule, exports from the United States to South Korea operate under a "presumed approval" principle, allowing for relatively unhindered trade.[44]

Quantum standards development. The Biden administration played a key role in initiating the creation of ISO/IEC JTC 3, a new committee on quantum technologies announced by the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO) on January 11, 2024. The committee is tasked with developing standards for quantum computing, sensing, communication, and related technologies, despite these fields still being in the early stages of development. The U.S. government actively lobbied for the establishment of the Joint Technical Committee, citing the need for a broad and coordinated international framework.

Unusually, the administration bypassed the typical process where the American National Standards Institute—the U.S. private sector's representative at ISO and IEC—would take the lead. Instead, the U.S. government directly engaged with other national standards bodies, such as those in the UK, Australia, and South Korea, to secure support for this initiative.[45] Compounding this break from tradition, the administration also positioned the National Institute of Standards and Technology, a federal agency, as the lead U.S. representative for the new committee, which is a role typically held by private-sector organizations with technical expertise. This approach represents a departure from the usual U.S. approach of fostering private sector–led, consensus-driven standards and raises concerns about overreach and misalignment with the needs of industry and academia. U.S. experts have contended that early government involvement may lock in standards before technologies are fully mature, potentially limiting their development and flexibility.[46] Bypassing traditional private sector–led processes could lead to confusion and conflicting messages about

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[43] Lara Seligman, "China Dominates the Rare Earths Market. This U.S. Mine Is Trying to Change That," *Politico Magazine*, December 14, 2022, https://www.politico.com/news/magazine/2022/12/14/rare-earth-mines-00071102.

[44] Jo He-rim, "U.S.' New Export Controls to Have Little Impact on Korean Businesses," *Korea Herald*, September 6, 2024, https://m.koreaherald.com/article/3469618.

[45] Nigel Cory, "The Biden Administration Overreacts Responding to China's Role in Setting Standards for Quantum Technologies," Information Technology and Innovation Foundation, July 2024, https://itif.org/publications/2024/07/29/the-biden-administration-overreacts-in-responding-to-china-s-role-in-setting-standards-for-quantum-technologies.

[46] Ibid.

the United States' position on international standards, ultimately undermining the collaborative approach that has historically defined U.S. leadership in this arena.

Conclusion

The United States has a unique opportunity to shape the global quantum ecosystem by deepening collaboration with South Korea. By aligning export controls, advancing joint R&D, and championing open, industry-led standards, the U.S. government can reinforce its leadership while ensuring that allied efforts remain coordinated and effective. Strengthening this partnership will enable the United States to better address the strategic and economic challenges posed by emerging quantum technologies and establish a foundation for broader policy actions to advance shared priorities with key allies.

Policy Options to Promote U.S.-ROK Cooperation on Quantum Technology

Jae Young Kwon and Hodan Omaar

In this era of intensifying global competition for advanced technology, strategic international cooperation can play an important role in enhancing the competitiveness of advanced technology. Quantum technology is one of the most promising dual-use technologies, but it requires coordinated cooperation with like-minded countries. The signing in 2023 of a joint statement on cooperation in quantum information science and technology between the United States and South Korea reflects their strong commitment to cooperation. Both countries are focusing their national capabilities to foster quantum technologies and agree that they should work together to create a global quantum ecosystem based on shared values. In order to vitalize cooperation and achieve synergy, the two countries should encourage several types of cooperation, including participation in government-level dialogues, joint R&D programs, and multilateral cooperation. The United States and the ROK should consider implementing the following policies.

Maintain government-level channels for promoting cooperation in quantum. The U.S. and ROK governments have for decades engaged in high-level science and technology dialogues, which stem from the U.S.-ROK S&T Agreement (1992). This has built shared values, such as fair competition, openness and transparency, accountability and reciprocity, and protection of intellectual property, and instilled mutual trust. In addition, the U.S.-ROK Next Generation Critical and Emerging Technologies Dialogue was launched in 2023 to accelerate cooperation in six strategic technologies, including quantum technology. As a follow-up of the dialogue, the National Institute of Standards and Technology and the Korea Research Institute of Standards and Science signed a memorandum of understanding in 2024 for collaboration on research and standard setting. This is a good channel for high-level cooperation in quantum because it is difficult for a bottom-up approach focused on individual scientists to reach a long-term agreement between national research institutions in both countries. The protection of quantum technology from adversaries and the development of regulations for the safe use of such technology and its application to military use will become important issues as quantum technology advances. These issues should be tackled through government-level dialogues and other channels of cooperation.

Promote joint R&D programs and consider raising joint funds for supporting quantum R&D collaboration. Quantum technology is still nascent and requires extensive research to be realized. Companies such as IBM and Google have shown superconducting quantum computers, but it remains unclear which approach of creating qubits will dominate. Regardless, the applications of quantum technology are numerous. Joint research and workforce exchanges between the United States and South Korea can accelerate the development of quantum technology and bring about various scientific innovations. In order for the two countries to benefit from joint research, they should work together to identify technological fields that are in need of R&D collaboration. Sustainable funding for joint research is also important.

Therefore, the United States and South Korea need to consider developing a mechanism for quantum R&D collaboration and raising dedicated funds for supporting joint quantum research. In particular, they should focus their collaboration on quantum-sensing technologies, a field with significant potential that remains underexplored in terms of joint efforts. To some extent, this is because of national security concerns. Quantum-sensing technologies have critical defense applications, making countries cautious about sharing breakthroughs. However, there are compelling reasons to carve out specific areas for collaboration, even in sensitive industries. By jointly identifying targeted, pre-competitive research opportunities for dual-use quantum-sensing technologies with clear commercial benefits, the United States and South Korea could promote innovation that benefits both nations and strengthens their position amid growing global competition from adversarial nations in this area. Indeed, China currently far and away leads the United States, the ROK, and their partners in the development of quantum-sensing technologies.

Actively engage in multilateral decision-making bodies to discuss implementing export controls for creating a healthy ecosystem for quantum technology. The United States has been imposing export controls on quantum computers, their components and materials, and related technologies since 2022. Although the targets are mainly China and Russia, these restrictions could affect other countries that are collaborating with the United States, including South Korea, by hindering projects that require the purchase and transport of products and parts that belong to the categories of quantum and semiconductors.

The United States and South Korea need to work together to ensure that export controls do not affect bilateral cooperation and can be used as a means to effectively restrain competitors. It is not yet clear whether the export controls will slow the pace of quantum technology development by competitors. Quantum technology supply chains have not been established, as multiple approaches for creating qubits are still under research. The uncertainty around quantum technology in its current stage makes it difficult for export controls to be effective. Therefore, allies and like-minded countries should be actively involved in identifying the key players in the supply chain of each qubit-creating process and work to design export controls that minimize the potential damages to allies.

To ensure that export controls do not inadvertently hinder U.S.-ROK cooperation, the two countries should collaborate on better understanding quantum supply chains and the impact of each country's export control policies. The trade dispute between South Korea and Japan in 2019 offers an important lesson for how the United States and South Korea should approach export controls on quantum technologies. In that dispute, Japan tightened controls on key materials needed for South Korea's semiconductor industry, causing major disruptions. This hurt both countries economically and risked giving competitors an edge. It also showed how poorly coordinated policies between partners can create unnecessary tension and weaken their ability to work together to address shared challenges. When it comes to quantum technologies, the United States and South Korea need to avoid repeating these mistakes. To prevent this from happening, they could establish a dedicated framework to harmonize export controls for quantum technologies. This includes regular consultations to share information, align policies, and develop joint approaches to managing sensitive technologies. Furthermore, both nations should engage with other like-minded countries, such as Japan, the Netherlands, and Germany, to build a plurilateral export control regime. This would ensure consistency and prevent gaps in enforcement that adversaries could exploit.

Champion open, industry-led, and consensus-based international standards for quantum technology. Developing common standards is one of the most important factors in securing technological leadership, as it affects the future entry of technologies into the global market. Standards are set through the consensus of international bodies. Although it might seem too early to discuss standard setting for quantum technology, both the United States and China are vying to become leaders in advanced technologies and have already released strategies for international standards.[47] Furthermore, there exist ongoing debates on the performance and measurement methods of quantum technology, which are prerequisites not only for commercialization but also for technological innovation. Contentious issues include how to define the performance of quantum computers and how to standardize measurement of single and entangled photons for quantum communication. In response to demands in the quantum science community, the IEC and ISO have approved the formation of a new joint technical committee (JTC 3) on quantum technologies, and its first plenary meeting was held in South Korea in May 2024. Approximately one hundred representatives from 22 countries participated, including the United States, the UK, Germany, and China. The new joint technical committee is expected to cover a broad scope of quantum technology, including quantum computing, simulation, metrology, and communication.

To ensure that quantum technologies integrate seamlessly into global markets, the United States, South Korea, and other U.S. allies must champion voluntary, transparent, and industry-led standard-setting processes. Through multilateral cooperation, these efforts will help facilitate the creation of a healthy quantum technology ecosystem in the future.

47 Matt Sheehan, Marjory S Blumenthal, and Michael R. Nelson, "Three Takeaways From China's New Standards Strategy," Carnegie Endowment for International Peace, October 28, 2021; and White House, *United States Government National Standards Strategy for Critical and Emerging Technology* (Washington, D.C., May 2023).

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