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NAVIGATING THE GLOBAL QUANTUM LANDSCAPE

Strategic Insights for Government Leaders



Paula Ganga

Visiting Fellow
Nicholas School of the Environment
Duke University

POTOMAC QUANTUM INNOVATION CENTER
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By proactively addressing risks and leveraging the opportunities quantum technology offers, government agencies can strengthen their capabilities in cybersecurity, threat detection, disaster response, and infrastructure protection.

Foreword

On behalf of the IBM Center for The Business of Government, and in collaboration with the Potomac Quantum Innovation Center (PQIC), we are pleased to release this new report: *Navigating the Global Quantum Landscape: Strategic Insights for Government Leaders* by Dr. Paula D. Ganga, Assistant Professor of Political Economy, Duke Kunshan University and Visiting Fellow at Duke University.



Daniel J. Chenok



George D. Thomas

Quantum technology represents one of the most consequential scientific and strategic developments for governments to address, now and in the future. The capacity of quantum computing to transform fields as diverse as materials science, pharmaceuticals, financial systems, and national security makes this a priority not only for researchers and industry, but for government leaders at every level. Yet the pace of global investment and innovation in quantum technology has accelerated far beyond what many in government have had the opportunity to fully absorb. Global investment in quantum technology surpassed $40 billion in 2024, with nations around the world committing vast public and private resources to prepare. In this environment, leveraging quantum computing for public value requires more than awareness—it calls for strategic action.

Too often, discussions of quantum technology focus narrowly on a single country or a single dimension of the technology. This report takes a broader view, analyzing five strategic elements: investment, innovation, education, security, and cooperation; and across five cases—the United States, China, the European Union, India, and Australia. The author presents a nuanced picture of global technology implementation that is both collaborative and complex. Some of the most important breakthroughs in quantum technology have emerged from international cooperation—a dynamic this report documents and builds upon.

This report provides government leaders and stakeholders with a concrete grounding in quantum policy and governance, and with an understanding of the real-world development and maturation of quantum technology itself. The quantum future does not reflect distant possibilities; current national strategies and actions have direct implications for how governments manage data, protect communications, and serve citizens.

The report's recommendations offer a clear and actionable roadmap. They include sustained investment in quantum research and innovation; expansion of quantum training programs within government agencies to prepare the workforce; prioritization of quantum-resistant encryption to protect critical communications and infrastructure; supply chain resilience through domestic investment and strategic cooperation with partner nations; and strengthened collaboration across academic institutions, private companies, and international allies. These recommendations recognize the budgetary, organizational, and geopolitical constraints that government managers face, while demonstrating that the cost of inaction exceeds the cost of sustained engagement.



The timeliness of this report is further affirmed by two Executive Orders issued by the Trump administration on June 22, 2026. Executive Order 14412, *Securing the Nation Against Advanced Cryptographic Attacks*, directs federal agencies to inventory and migrate their high-value and high-impact systems to NIST-approved post-quantum cryptography standards, establishes a government-wide post-quantum cryptography (PQC) migration coordination structure, and sets binding deadlines of 2030 and 2031, respectively, for key-establishment and digital-signature transitions. It also directs engagement with critical infrastructure owners and international partners to align on quantum-resistant encryption.

In 2018, President Trump signed the National Quantum Initiative Act into law, establishing the first whole-of-government strategy for American leadership in quantum technology. Executive Order 14413, *Ushering in the Next Frontier of Quantum Innovation*, expands and updates the whole-of-government strategy to accelerate the development, deployment, and commercialization of quantum computing, sensing, and networking technologies. It creates the Quantum Computer for Application Development and Discovery Science effort, directs the development of an updated National Quantum Strategy, calls for expanded federal quantum workforce recruitment and training programs, directs supply-chain resilience planning, and tasks the Departments of State and Commerce with aligning international partnerships to advance and protect American leadership in quantum information science and technology. Together, these Executive Orders place quantum readiness at the center of national security and technology agendas and make the analysis and recommendations in this report more timely than ever.

For public administrators, agency leaders, and policymakers working to prepare government operations for the quantum era, this report provides a key foundation. As recently recognized by the United Nations, governments are at an inflection point with regard to quantum progress—one that will shape economic competitiveness, national security, and public services for decades to come. The United States has invested significantly in quantum technology and built strong research infrastructure, an entrepreneurial ecosystem, and international partnerships that position it well.

This report builds on a growing body of IBM Center work focused on quantum technology and its implications for government. That work includes *Quantum Computing for Public Value: Insights from Australia*; the chapter "Quantum Technology Challenge: What Role for the Government?" in the IBM Center book *Transforming the Business of Government: Insights on Resiliency, Innovation, and Performance*; and *Nation-State Activity in the Age of Artificial Intelligence and Quantum Computing*. Together, these publications reflect the IBM Center's sustained commitment to equipping government leaders with the knowledge and frameworks they need to navigate the quantum landscape effectively and responsibly.

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Executive Summary

Quantum computing represents the next frontier for technological innovation. The United States government has invested substantial resources to develop a robust network of public and private actors at the global forefront of this technology.

Other countries across the world have made similar investments, and cooperation has flourished. This report examines cross-national advances in quantum technology and highlights lessons learned that can be shared and applied to continue progress in this crucial sector. It provides an overview of the state of the field of quantum technologies and offers actionable insights on how to foster cooperation among international players in quantum technology while also supporting the U.S. government's progress in developing this cutting-edge technology.

Snapshot in Time—Global Investment in Quantum Computing Thus Far

Global investment in quantum computing has been increasing rapidly. The U.S. government has invested around $5 billion. China has pledged $15 billion for quantum technology, followed by the EU with $10 billion.[1]

Quantum technology breakthroughs are already in use today. In the U.S., IBM has unveiled increasingly complex cutting-edge quantum chips: Eagle with 127 qubits (2022-2023), Heron (currently in Rev 3) at 156 qubits (2024), and Nighthawk with 120 qubits (2025), leading to greater computational throughput.[2] These innovations have led to direct applications in materials science and high-energy physics at national laboratories, as well as in medical sciences and healthcare, such as at the Cleveland Clinic.

China has made similar discoveries, achieving breakthroughs in both photon- and superconducting-qubit quantum computing. China has also launched several quantum satellites, notably Micius in 2016 and Jinan in 2022. Across Europe, significant advances have been made in several key technologies essential for quantum computing, including cryogenics, specialized cables and connectors, and the tools and techniques needed to integrate quantum computers with high-performance computing systems.

These investment figures and recent innovations underscore the importance of this technology, and the need to explore the global quantum ecosystem more deeply. This report sets the stage by providing background information on quantum technology, and the main sectors of development and innovation for this evolving technology. The report then addresses five strategic elements in the development of quantum across five countries.

1. Fredrik Erixon, Andrea Dugo, Dyuti Pandya, and Oscar du Roy, "Benchmarking Quantum Technology Performance: Governments, Industry, Academia and their Role in Shaping our Technological Future," *Policy Brief*, no. 06 (March 2025), https://ecipe.org/publications/benchmarking-quantum-technology-performance/.
2. Ryan Mandelbaum, Scaling for quantum advantage and beyond, 12 Nov 2025, https://www.ibm.com/quantum/blog/qdc-2025.

- **Investment**, as both public and private resources can significantly impact a country's advancement in quantum technology.
- **Innovation**, as the fruit of the previous step, with the report exploring what each country contributed to the global quantum sector.
- **Education** on quantum, and strategies for integrating this technology by the future workforce. Education is critical not just to create an educated labor supply, but also to foster a robust market for these products. Not knowing how to use these products will limit their potential to impact future markets.
- The final two sections will explore two trends that will shape the future of this technology: **security** and **cooperation**. How countries balance placing safeguards around quantum technology with leveraging the value of cooperation can have a profound impact on harnessing the power of quantum innovation.

Each of these strategic elements will be examined across five different global players within the evolving quantum ecosystem, to illustrate the rich diversity of approaches and contributions in this field.

- **The U.S.** operates as a technological leader with established research infrastructure and market-driven innovation, positioning itself to shape quantum technology development through both private sector advancement and strategic public investment. The U.S. benefits from a decentralized and federated innovation ecosystem supported by a robust investment infrastructure.
- **China** employs a comprehensive state-directed strategy, mobilizing significant government resources and coordinated planning to rapidly develop quantum capabilities across multiple technological domains.
- **The European Union** pursues a collaborative framework emphasizing multilateral cooperation and shared research initiatives, leveraging its collective scientific expertise while maintaining strong public investment in quantum research.
- **India** represents an emerging quantum player focused on building foundational capabilities and research capacity, demonstrating how developing economies can strategically enter advanced technology sectors through targeted investments in education and infrastructure.
- **Australia** showcases a nation with strong scientific traditions and educational institutions working to translate research excellence into commercial quantum applications, highlighting both the opportunities and challenges facing innovation-rich economies in emerging technology markets.



The report's primary recommendations are as follows:

- **Support Scientific Innovation:** Innovation represents the main goal in the pursuit of quantum technology. Public investment in scientific innovation can be complemented by private investment to bring those discoveries to market.
- **Expand Quantum Training Programs:** Government agencies can incorporate quantum education and training initiatives to prepare personnel for the emerging technological landscape.
- **Invest in Quantum-Resistant Encryption:** Government agencies should prioritize research and development of quantum-resistant cryptographic methods to safeguard critical communications and data.
- **Protect the Supply Chain:** Securing national supply chains constitutes a key step to continue building the quantum innovation system.
- **Strengthen Collaboration:** Governments can establish partnerships with academic institutions, private companies, and international allies to advance quantum research, share best practices, and develop a quantum-capable workforce.

This comparative examination of the quantum sector worldwide reveals that the U.S. has the opportunity to continue and expand its quantum investment. Sustained commitment to quantum technologies is essential for maintaining technological leadership. Governments that reduce their focus or investment in this critical field risk facing periods of technological catch-up that can fundamentally alter their position in the global innovation landscape.

Introduction

The development of quantum technology has the potential to reshape the world's economic landscape. While the U.S. has already invested significant resources in developing quantum information science (QIS), the scale and pace of global investment in this cutting-edge technology necessitate continued and expanded efforts to maintain technological advancement.

Given the importance of quantum, global investment has been increasing rapidly—surpassing $40 billion in 2024, with investments in quantum technology startups reaching an all-time high of $15 billion.[3] Investment is led by China, the European Union, and the United States, with Japan, the United Kingdom, Canada, and India emerging as other prominent players. China's public investment accounts for $15.3 billion,[4] with the EU in second place, at $10 billion, followed by the United States, Japan, and the United Kingdom.[5]

Examining the development of quantum technology from a comparative perspective has importance for several reasons.

- In terms of reach, quantum technology could bring widespread change. The May 2022 White House National Memorandum acknowledged the importance of quantum computing for fields as diverse as materials science, pharmaceuticals, finance, and energy.[6] When integrated with advances in artificial intelligence, quantum artificial intelligence could compound the disruptive capacity of both technologies.[7] In February 2026, the Department of Energy and its 17 National Laboratories, in collaboration with the White House Office of Science and Technology Policy and 55 private companies, created the Genesis Mission—meant to become the world's most powerful scientific platform that unites the world's most powerful supercomputers, AI systems, and emerging quantum technologies with the nation's most advanced scientific instruments.[8]
- While industry-revolutionizing, quantum technology can also raise risks when wielded with nefarious intent. Quantum computing could enable breaking any commonly used encryption, and could "jeopardize civilian and military communications, undermine supervisory and control systems for critical infrastructure, and defeat security protocols for most internet-based financial transactions."[9] Successful attacks against traditional algorithms could compromise financial systems, critical infrastructure, and military installations.[10] Understanding the state of quantum development worldwide can help the U.S. government accelerate efforts to quantum-proof its encryption algorithms.[11]

3. Mandelbaum, Scaling for quantum advantage and beyond, 12 Nov 2025.
4. China's quantum investment levels are difficult to verify and are not directly comparable to U.S. or EU budget disclosures due to differences in accounting practices, transparency, and governance structures.
5. Mandelbaum, Scaling for quantum advantage and beyond, 12 Nov 2025.
6. "National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems," The White House, May 4, 2022, https://bidenwhitehouse.archives.gov/briefing-room/statements-releases/2022/05/04/national-security-memorandum-on-promoting-united-states-leadership-in-quantum-computing-while-mitigating-risks-to-vulnerable-cryptographic-systems/.
7. Richard D. Taylor, "Quantum artificial intelligence: a 'Precautionary' U.S. approach?" *Telecommunications Policy* 44, no. 6 (2020): 101909.
8. "DOE Launches Genesis Mission Consortium," February 9, 2026, https://fedscoop.com/energy-department-genesis-mission-consortium-private-sector-partners/.
9. The White House 2022. https://www.presidency.ucsb.edu/documents/memorandum-promoting-united-states-leadership-quantum-computing-while-mitigating-risks.
10. Tahsin Saadi Sedik, Majid Malaika, Michael Gorbanyov, and Jose Deodoro, "Quantum Computing's Possibilities and Perils," *International Monetary Fund*, September 2021, https://www.imf.org/en/Publications/fandd/issues/2021/09/quantum-computings-possibilitiesandperils-deodoro.
11. "NIST Announces First Four Quantum-Resistant Cryptographic Algorithms," NIST, July 05, 2022, https://www.nist.gov/news-events/news/2022/07/nist-announces-first-four-quantum-resistant-cryptographic-algorithms.

- The quest to harness the power of quantum technology is global.[12] Although the U.S. has a lead through its early investments and highly educated workforce, other actors have been catching up. For example, China has outpaced the United States in various applications such as quantum networks and quantum processors,[13] and the European Union has also invested substantial resources across a decentralized network of research institutes among EU member states.[14]

While the terms *quantum*, *quantum computing*, and *quantum technology* are often used interchangeably, this report deals with quantum technology more broadly. Within this scope, there are three main branches.

1. **Quantum Sensing** focuses on the development of ultra-sensitive devices capable of measuring minute changes in motion and electromagnetic fields. Possible applications include medical imaging and diagnosis, navigation, radar, geophysics, and more.[15]
2. **Quantum Communication** enables ultra-fast and highly secure data transmissions. This would allow virtually unhackable communications, a technology sought after by governments, militaries, financial firms, and others.
3. **Quantum Computing** has garnered the most attention globally, and promises to be the most transformative of the three. Quantum computers equipped with enough qubits can perform complex calculations, at speeds vastly surpassing the most advanced supercomputers in use today.

While competition may attract headlines across much quantum technology reporting,[16] international cooperation represents the most important force in this field. This affects how regulation[17] and development—some of the most interesting breakthroughs have come from collaboration.[18] As quantum technology reaches a level of complexity that could threaten cybersecurity, governments and militaries may impose stricter controls and regulations to secure critical technologies – even while scholars prioritize scientific collaboration.

This report examines five strategic elements in this field, and compares government and private-sector actions across the United States, China, the European Union, India, and Australia (though more than five countries have quantum programs). The table below summarizes these comparisons. Each case explores the rich diversity within quantum technology.

12. Ethan Steele, "Quantum Supremacy Race: How Global Powers are Vying for Quantum Dominance," *Medium*, October 4, 2023, https://medium.com/@steeleethan22/quantum-supremacy-race-how-global-powers-are-vying-for-quantum-dominance-85c5c47d78fc.
13. Thomas Corbett and Peter W. Singer, "China May Have Just Taken the Lead in the Quantum Computing Race," *Defense One*, April 14, 2022, https://www.defenseone.com/ideas/2022/04/china-may-have-just-taken-lead-quantum-computing-race/365707/; Vivek Wadhwa and Mauritz Kop, "Why Quantum Computing Is Even More Dangerous Than Artificial Intelligence," Foreign Policy, August 21, 2022, https://foreignpolicy.com/2022/08/21/quantum-computing-artificial-intelligence-ai-technology-regulation/.
14. Jonathan Keane, "Is quantum computing the next technology on the EU's regulation agenda?," *Euronews*, January 30, 2024, https://www.euronews.com/next/2024/01/30/is-quantum-computing-the-next-technology-on-the-eus-regulation-agenda.
15. Brian Hart, Bonny Lin, Samantha Lu, Hannah Price, Yu-jie (Grace) Liao, and Matthew Slade, "Is China a Leader in Quantum Technologies?" *China Power*, January 31, 2024, https://chinapower.csis.org/china-quantum-technology/.
16. Corbett and Singer, 2022; Steele, 2023.
17. Keane, "Is quantum computing the next technology on the EU's regulation agenda?"
18. For example, in 2022, the most advanced hybrid room-temperature computer was developed in Germany and is housed at a supercomputing facility in Australia. (Nick Flaherty, "First room-temperature quantum computer in supercomputing centre," June 2, 2022, https://www.eenewseurope.com/en/first-room-temperature-quantum-computer-in-supercomputing-centre/) Similarly, in 2025, Australian firm Quantum Brilliance installed a diamond-based hybrid computer system at the Department of Energy's Oak Ridge National Lab Leadership Computing Facility in Tennessee. (Coury Turczyn, "Quantum Brilliance, ORNL Pioneer Quantum-Classical Hybrid Computing," Oak Ridge national Laboratory, September 2, 2025, https://www.olcf.ornl.gov/2025/09/02/quantum-brilliance-ornl-pioneer-quantum-classical-hybrid-computing/).

Table 1. Summary of report findings

Case study	Public Investment[19]	Advantages	Challenges
U.S.	$5bn	Most vibrant start-up ecosystem	Decentralized, multi-party, and federated approach, creating ambiguity and breaks in funding
China	$15.3bn	Huge public investment	Highly centralized approach
EU	$10bn	Great scientific ecosystem	No clear leadership outside the academic sector; a change in focus can drain resources
India	$750m[20]	Ability to leverage cooperation	New to the sector
Australia	$2bn[21]	Public investment and tradition for innovation	Brain drain and focus on commercialization

The comparative analysis of quantum development across other countries suggests that U.S. public managers at all levels of government would benefit from a greater understanding of advances in quantum technology, and of actionable steps that can help the U.S. harness quantum advantages while minimizing risks.

19. Erixon, Dugo, Pandya, and du Roy, "Benchmarking Quantum Technology Performance."
20. Physics World, "India must boost investment in quantum technologies to become world leader, says report," 28 April 2025, https://physicsworld.com/a/india-must-boost-investment-in-quantum-technologies-to-become-world-leader-says-report/.
21. "Australia Positioned to Lead Global Quantum Race with $2 Billion Investment," Quantum Australia, n.d. https://quantum-australia.com/news/australia-positioned-lead-global-quantum-race-2-billion-investment.



What Are Quantum Technologies?

Quantum physics differs from classical physics in several ways, but at its most basic level, computation is done in a fundamentally different manner. In classical physics and in computers based on its principles, information is stored as binary bits, which can take the values 0 or 1. In quantum physics, quantum bits (or qubits) can represent both zero and one (or a linear combination of the two) at the same time. As noted by physicist Michio Kaku, instead of "tiny transistors, [qubits] compute on the tiniest possible object, the atoms themselves."[22] This phenomenon of superposition enables quantum computers to find faster solutions to mathematical problems that currently require significantly more time and computing power on classical computers.[23]

Computational speed reflects one of the first crucial improvements this technology will bring about. Comparing complex computational tasks to finding the way out of a maze, a classical computer attempts to solve the maze by following every path in sequence until finding a solution. In contrast, superposition enables a quantum computer to explore all paths simultaneously.[24] This drastically reduces the time to resolution.

Increasing the number of qubits dramatically increases the processing speed of calculations. In an example provided by Deodoro et al., "two traditional binary bits are needed to match the power of a single qubit; four bits are required to match two qubits; eight bits are needed to match three qubits; and so on. It would take about 18 quadrillion bits of traditional memory to model a quantum computer with just 54 qubits. A 100-qubit quantum computer would require more bits than there are atoms on our planet. And a 280-qubit computer would require more bits than there are atoms in the known universe."[25]

Moreover, various quantum algorithms offer substantial improvements in computational speed relative to classical algorithms. For example, Grover's and Shor's algorithms each promise a polynomial and an exponential speedup, respectively, over a classical computer. A polynomial speedup occurs when a quantum computer can solve a problem in time T, compared to a classical computer, which would require a longer time of T^2. In contrast, for an exponential speedup, a quantum computer still only needs time T, but the classical computer needs time 2^T (for example) or an exponentially growing function of *T*. So, if *T* is 100, the difference will be between 100 and 2^{100}.[26]

Compared with current supercomputers, which sometimes need as much electricity as a small town, a functioning quantum computer can solve problems in a few hours with much less energy. According to studies conducted by NASA, Google, and the Oak Ridge National Laboratory, a quantum computer might only require 0.002 percent of the energy consumed by a classical supercomputer to perform the same task.[27] In a paper comparing the performance of classical and quantum computers in solving the quadratic assignment problem,[28] the quan-

22. Michio Kaku, *Quantum Supremacy. How the Quantum Computer Revolution Will Change Everything* (2024, Penguin Random House) p. 4.
23. World Economic Forum, *State of Quantum Computing: Building a Quantum Economy*, September 2022, pp. 5-6, https://www.weforum.org/reports/state-of-quantum-computing-building-a-quantum-economy/.
24. Charlie Campbell, "Quantum Computers Could Solve Countless Problems—And Create a Lot of New Ones," *Time*, January 26, 2023, https://time.com/6249784/quantum-computing-revolution/.
25. Jose Deodoro, Michael Gorbanyov, Majid Malaika and Tahsin Saadi Sedik, "Quantum Computing and the Financial System: Spooky Action at a Distance?", *IMF Working Papers* (2021): 6, https://www.imf.org/-/media/files/publications/wp/2021/english/wpiea2021071-print-pdf.pdf.
26. Robin Kothari, "Quantum speedups for unstructured problems: Solving two twenty-year-old problems," *Microsoft Research Blog*, May 4, 2020, https://www.microsoft.com/en-us/research/blog/quantum-speedups-for-unstructured-problems-solving-two-twenty-year-old-problems/?msockid=032653060285640808 6e40f9038d65ec.
27. Tin Lok Wu, "What is Quantum Computing and How Can it Help Mitigate Climate Change?," *Earth.Org*, August 22, 2022, https://earth.org/what-is-quantum-computing/#:~:text=In%20addition%20to%20its%20functions,to%20perform%20the%20same%20task.
28. An example of a quadratic assignment problem is trying to minimize energy consumption when moving goods between n facilities and n locations. The study in the example asked to solve the problem with 20 facilities and locations.

tum computer generated a correct answer in about 700 seconds, whereas the classical computer still had not finished computing within the time limit of 12 hours.[29]

The real-world applications of this computational breakthrough can revolutionize activity across diverse fields such as materials science, pharmaceuticals, medical research, finance, and energy.

- Materials science is driven by sophisticated simulations. With the increasing power of quantum computing, materials science simulations can be completed faster, enabling the discovery of manufacturing innovations, new battery catalysts, and even new materials for use in satellites and space exploration.[30]
- In medical research, quantum computing can aid in biomedical and genetic studies; and in pharmaceutical development, QC can facilitate the simulation of larger, more complex molecules during the drug development stages.[31] As a recent example, the Cleveland Clinic and IBM deployed the Discovery Accelerator Center, a quantum-enabled facility dedicated to biomedical research.[32] The IBM Quantum System One computer currently helps screen and optimize drugs targeted to specific proteins, and creates a quantum-enhanced prediction model for cardiovascular risk after non-cardiac surgery.[33]
- In finance, QIS can create as much as $622 billion in value from applications in corporate banking, risk and cybersecurity, retail banking, payments, wealth management, investment banking, operations, and finance.[34]
- In energy, quantum computers will not only employ much less energy than supercomputers currently in use—their computational capacity will enable practical applications such as energy forecasting and optimization in renewable energy systems with variable weather patterns, or in predicting energy needs associated with EV charging patterns.[35] These essential energy uses can overwhelm classical systems, and QC can provide solutions and planning.

Despite ongoing development, breakthroughs in quantum technology have accelerated in recent years, dramatically shortening the timeline for subsequent advances.

29. Akshay Ajagekar, Fengqi You, "Quantum computing for energy systems optimization: Challenges and opportunities," *Energy* 179 (2019): 76-89.
30. "Quantum Leap In Material Science," Tech Briefs, March 1, 2024, https://www.techbriefs.com/component/content/article/50221-quantum-leap-in-material-science.
31. Matthias Evers, Anna Heid, and Ivan Ostojic, "Pharma's Digital Rx: Quantum Computing In Drug Research And Development," *McKinsey*, June 18, 2021, https://www.mckinsey.com/industries/life-sciences/our-insights/pharmas-digital-rx-quantum-computing-in-drug-research-and-development; Georges-Olivier Reymond, "How quantum computing is changing drug development at the molecular level," *World Economic Forum*, January 3, 2025, https://www.weforum.org/stories/2025/01/quantum-computing-drug-development/.
32. Margie Graves, *Nation-State Activity in the Age of Artificial Intelligence and Quantum Computing*, The IBM Center for Business of Government, December 11, 2024, https://businessofgovernment.org/blog/nation-state-activity-age-artificial-intelligence-and-quantum-computing.
33. Paul Smith-Goodson, "Cleveland Clinic And IBM Launch World's First Quantum Computer Dedicated To Healthcare Research And Biomedical Discoveries," *Forbes*, March 21, 2023, https://www.forbes.com/sites/moorinsights/2023/03/21/cleveland-clinic-and-ibm-launch-worlds-first-quantum-computer-dedicated-to-healthcare-research-and-biomedical-discoveries/.
34. Martina Gschwendtner, Nicole Morgan, and Henning Soller, "Quantum technology use cases as fuel for value in finance," *McKinsey*, October 23, 2023, https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/tech-forward/quantum-technology-use-cases-as-fuel-for-value-in-finance.
35. Georges-Olivier Reymond, "See how quantum computing can revolutionize energy forecasting and optimization," *World Economic Forum*, January 8, 2025, https://www.weforum.org/stories/2025/01/quantum-computing-energy-forecasting/.

Key Findings

- The revolutionary potential of quantum technology is clear. To best understand how the U.S. government can harness that potential, this report identifies five strategic elements—investment, innovation, education, protection, and cooperation—that together define the landscape of national engagement with quantum development. For each element, the report examines advancements and challenges across five countries identified as global players in the quantum arena: the U.S., China, the EU, India, and Australia. The following sections demonstrate that the roles government can and should play in quantum technology are multifaceted. To maximize the benefits of this technology, several key roles and recommendations emerge from—and build upon existing government initiatives.
- This account begins by examining the investments that major players have made in their quantum sector, while also considering the role governments and markets have played in these investments. The U.S. can continue investing in the development of this technology. While China has taken the lead in state investments along with the EU, American leadership can combine the strength of government support with the robustness of the private market to continue its leadership.
- Next, the report examines the state of innovation that this investment has spurred. The report catalogs the main achievements of each country to showcase where various dimensions of quantum technology are developed, and where the U.S. can lead in innovation.
- For innovation to occur, education represents a crucial step. The report demonstrates how each major country is building a quantum-ready workforce for future technological advantage. Incorporating quantum education and training initiatives across government agencies can prepare personnel for the emerging technological landscape.
- The report also addresses the international dimension by examining steps toward protecting the quantum sector versus fostering cooperation. The main recommendations support protection through quantum-resistant cryptography, as well as supply chain resilience to ensure continued American innovation.
- The final section assesses the steps toward leveraging cooperation. The U.S. can leverage cooperation to accelerate innovation through partnerships with academic institutions, private companies, and international allies, advancing quantum research, sharing best practices, and developing a quantum-capable workforce.



Key Strategic Elements

This section of the report addresses five strategic elements in the development of quantum by governments in the U.S. and globally and makes recommendations for U.S. government progress in addressing each element.

- **Investment**, as both public and private resources can significantly impact a country's advancement in quantum technology.
- **Innovation**, as the fruit of the previous step, with the report exploring what each country contributed to the global quantum sector.
- **Education** on quantum, and strategies for integrating this technology by the future workforce. Education is critical not just to create an educated labor supply, but also to foster a robust market for these products. Not knowing how to use these products will limit their potential to impact future markets.
- **Security** and **Cooperation,** which reflect two trends that will shape the future of this technology.

INVEST

Investment in quantum computing is among the most fundamental determinants of technological progress in this emerging field. The development of quantum technologies requires substantial financial resources due to the complexity of quantum systems, specialized research and development equipment, and long lead times between initial research breakthroughs and commercial applications. For costly cutting-edge technologies, government investment is particularly vital. While government investment provides the foundation, private sector funding accelerates the translation of quantum research into commercial applications.

Insufficient investment can lead to technological dependence and a reduced influence in setting international quantum standards and protocols. Conversely, strategic investment provides a first-mover advantage and can position governments as leaders in defining the future direction of quantum technologies and their applications. This section examines the major government players investing in quantum technologies and how this investment has been supplemented by private investment. It also explores how a lack of such investment could delay the market readiness of quantum technology.



United States

The U.S. government established the National Quantum Initiative (NQI) Act in 2018 to support the development of quantum technology,[36] which implemented a framework for research and development (R&D) in this sector and allocated a $1.2 billion budget for several initiatives over a five-year period (2019-2023).[37] The budget has been allocated to three key agencies: the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the Department of Energy (DOE), which runs the National Laboratory network.

36. "About the National Quantum Initiative," National Quantum Coordination Office, accessed December 21, 2025, https://www.quantum.gov/about/#NQIA.
37. The NQI is being discussed for reauthorization in 2025 (Matt Swayne, "U.S. Quantum Industry Leaders Press Congress To Expand Support," *Quantum Insider*, May 8, 2025, https://thequantuminsider.com/2025/05/08/u-s-quantum-industry-leaders-press-congress-to-expand-u-s-support/#:~:text=At%20a%20May%207%20House%20Science%20Committee%20hearing%2C,Initiative%20to%20maintain%20U.S.%20leadership%20in%20quantum%20technologies.).

Some of the important funding initiatives commanded large sums of support:

- The DOE received a total of $245 million, including $125 million for five of the DOE-led National QIS Research Centers.[38] In 2025, this funding was renewed with $625 million, split between the five centers.[39]
- The National Institutes of Health's Office of Data Science received $85 million to implement a new pilot program with the DOE to study the role of quantum computing in biomedical sciences.[40]
- The National Science Foundation (NSF) received $235 million to continue QIS R&D.
- The National Institute of Standards and Technology (NIST) funding for QIS reached $54 million.[41]
- The Department of Defense saw several program increases such as $30 million for the U.S. Air Force (USAF) Ion Trap Quantum Computing, $10 million for the USAF Quantum Network Testbed, $5 million for the USAF Secure Quantum Computing Facility, $30 million for university-based quantum materials applied research, $10 million for Army quantum technologies for armament systems, and $1.4 million for quantum computing technologies.[42]

When the five-year review was done, the December 2024 NQI annual report evaluated the quantum government spending at $456 million in FY 2019, $690 million in FY 2020, $851 million in FY 2021, $1,041 million in FY 2022, and $1,036 million in FY 2023, followed by $1,006 million of enacted budget authority for FY 2024 and a requested budget authority of $998 million for FY 2025.[43] For 2026, there is bipartisan support for doubling the funding for quantum technology, although the Trump administration's proposed budget did not include a request for additional funding.[44]

One of the greatest strengths of the U.S. quantum sector is not just the robust government support and world-class educational and research institutions that conduct basic research in this field, but also the private sector that later develops commercial applications of new technologies through startups and venture funding. Private funding has been increasing steadily every year, with a high of nearly $963 million in 2022. In 2024, these numbers were surpassed by startups raising over $1.5 billion in venture funding.[45] In 2025, private investments continued to surge, with $1.25 billion was raised in Q1 and $1.16 billion in Q2.[46]

38. Peter Villano, "More Money, More Guidance for Quantum Information Science R&D," *Federal Budget IQ*, January 27, 2023, https://federalbudgetiq.com/insights/more-money-more-guidance-for-quantum-information-science-rd/.
39. Madison Alder, "DOE announces $625 million to continue quantum research centers," *Fedscoop*, November 4, 2025, https://fedscoop.com/doe-announces-625-million-continue-quantum-research-centers/.
40. U.S. Senate, "Congressional Record. PROCEEDINGS AND DEBATES OF THE 117th CONGRESS, SECOND SESSION," December 20, 2022, S8553, Vol. 168, No. 198—Book II, p. S8885, https://www.congress.gov/117/crec/2022/12/20/168/198/CREC-2022-12-20-pt2-PgS8553-2.pdf.
41. U.S. Congress, "DIVISION B—COMMERCE, JUSTICE, SCIENCE, AND RELATED AGENCIES APPROPRIATIONS ACT, 2023," p. 11-12, https://www.appropriations.senate.gov/imo/media/doc/Division%20B%20-%20CJS%20Statement%20FY23.pdf.
42. U.S. Congress, "DIVISION C - DEPARTMENT OF DEFENSE APPROPRIATIONS ACT, 2023," p. 89A, p. 94B, https://www.appropriations.senate.gov/imo/media/doc/Division%20C%20-%20Defense%20Statement%20FY23.pdf.
43. National Quantum Initiative Supplement to the President's FY 2025 Budget, December 2024 https://www.quantum.gov/wp-content/uploads/2024/12/NQI-Annual-Report-FY2025.pdf, p. 3.
44. Matt Swayne, "Congress Urged to Double Quantum Funding to Compete With China," *Quantum Business*, May 19, 2025, https://thequantuminsider.com/2025/05/19/congress-urged-to-double-quantum-funding-to-compete-with-china/; Justin Doubleday, "Workforce, supply chain factor into reauthorizing National Quantum Initiative," *Federal News Network*, 22 January 2026, https://federalnewsnetwork.com/congress/2026/01/workforce-supply-chain-factor-into-reauthorizing-national-quantum-initiative/.
45. Chris Metinko, "Quantum Computing Funding Hits Record High With Apparent AI Boost," *Crucnbase News*, November 14, 2024, https://news.crunchbase.com/venture/quantum-computing-funding-record-high-ai-quantinuum/.
46. Matt Swayne, "Q1 2025 Quantum Technology Investment: What's Driving The Surge In Quantum Investment?," *Quantum Insider*, August 11, 2025, https://thequantuminsider.com/2025/05/27/q1-2025-quantum-technology-investment-whats-driving-the-surge-in-quantum-investment/; Matt Swayne, "Investor Sentiment Pivots As Funding, M&A And Research Advances Spark Interest During Q2 2025," *Quantum Insider*, July 14, 2025, https://thequantuminsider.com/2025/07/14/investor-sentiment-pivots-as-funding-ma-and-research-advances-spark-interest-during-q2-2025/.



China

China has taken a state-led approach to funding and conducting R&D for quantum technologies. This stands in contrast to the approach taken by other leading quantum technology players, where the private sector has typically played a greater role. In his most notable speech on technology in October 2020, Chinese Premier Xi Jinping said that "accelerating the development of quantum technology plays a very important role in promoting high-quality development and ensuring national security."[47] While central coordination enables rapid mobilization, it may also introduce inefficiencies such as redundant investments and reduced flexibility compared with more market-driven ecosystems.

China has made sizeable investments in quantum technology and has achieved considerable success, with some even suggesting it has now taken the lead in this field. Quantum R&D has been identified as a strategic industry and area for innovation in China's Five-Year Plans since the 11th plan (2006-10) and in the 'Made in China 2025' policy.[48] In the 14th Five-Year Plan (2021-25), the Chinese government announced an investment of $15.3 billion.[49] However, these figures are not uniformly accepted, with other studies putting the range of Chinese government investment between $4 billion and $17 billion.[50] The true extent of China's investment is difficult to determine due to the opacity of its government spending.[51]

In terms of private initiatives, the city of Hefei stands out as the Chinese capital of quantum science. Yunfei Road is nicknamed "Quantum Avenue," where more than 20 startups are headquartered—including QuantumCTek and Origin Quantum, two spin-offs of the University of Science and Technology of China that specialize in quantum computing.[52]

Despite the large number of reported Chinese quantum companies, one study found that only 14 private-sector firms can be identified as making significant contributions to quantum technology, comprising nine startups and five major tech companies.[53] However, these numbers also include companies that have since exited the sector, such as Alibaba and Baidu.[54] According to reported estimates, between 2001 and 2022, Chinese quantum startups received only $482 million from the private sector.[55] That is a fraction of private-sector investment in the United States, which led the world with an estimated $3.3 billion in non-government sources.

47. "Xi Jinping: Speech at the Symposium with Scientists," *Xinhua*, September 11, 2020, http://www.xinhuanet.com/politics/2020-09/11/c_1126483997.htm.
48. Johnny Kung, "A Quantum Revolution: Report on Global Policies for Quantum Technology," *CIFAR*, April 7, 2021, https://cifar.ca/cifarnews/2021/04/07/a-quantum-revolution-report-on-global-policies-for-quantum-technology/.
49. "Quantum Technology Monitor 2023," McKinsey & Company, 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.
50. "Chinese Quantum Companies And National Strategy 2023," Quantum Insider, April 21, 2024, https://thequantuminsider.com/2023/04/13/chinese-quantum-companies-and-national-strategy-2023/.
51. Sydney J. Freedberg Jr., "China's investing billions in quantum R&D, but is Beijing making some bad bets?," *Breaking Defense*, February 5, 2025, https://breakingdefense.com/2024/02/chinas-investing-billions-in-quantum-rd-but-is-beijing-making-some-bad-bets/.
52. Edward Parker, Daniel Gonzales, Ajay K. Kochhar, Sydney Litterer, Kathryn O'Connor, Jon Schmid, Keller Scholl, Richard Silberglitt, Joan Chang, Christopher A. Eusebi, and Scott W. Harold, *An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology*, (RAND, February 2, 2022), https://www.rand.org/pubs/research_reports/RRA869-1.html.
53. Hodan Omaar and Martin Makaryan, "How Innovative Is China In Quantum?," *ITIF*, September 9, 2024, https://itif.org/publications/2024/09/09/how-innovative-is-china-in-quantum/.
54. Lily Ottinger, "China's Quantum Gamble," November 19, 2024, https://www.chinatalk.media/p/chinas-quantum-gamble.
55. China Power Team, "Is China a Leader in Quantum Technologies?" China Power. August 14, 2023. Updated January 31, 2024. Accessed December 21, 2025. https://chinapower.csis.org/china-quantum-technology/.

China's startup ecosystem is less vibrant. Although promising, Origin Quantum and QuantumCTek are closely linked to the state-funded academic environment at the University of Science and Technology of China.

Moreover, the exit of large Chinese tech companies from quantum research signals a broader push by the state to tighten control over Chinese quantum research and development. Both Alibaba and Baidu have shut down their quantum research divisions and transferred their assets to state-linked institutions. Baidu donated its quantum research facilities to the Beijing Academy of Quantum Information Sciences, while Alibaba transferred its quantum lab to Zhejiang University.[56] By centralizing quantum research within state-affiliated institutions, the government is not only reducing the role of private companies but also directing the course of innovation.[57] The establishment of China Telecom Quantum Group suggests that China is setting up a new state-owned enterprise (SOE) to take control of a given sector, the quantum industry in this case.[58] The SOE's ability to produce innovation and attract funding remains to be seen.

Unlike other lead players, China focuses on the immediate and secure applications of quantum communications, a more mature set of technologies with a narrower market scope.[59] Overall, China's strategic focus on near-term quantum technologies enables it to lead in sectors of this technology that are closer to market readiness. Some experts noted that by prioritizing these immediate gains, China may be overlooking the future potential of the technology.[60]

The coordination of investments in technology under the state umbrella has continued. During the March 2025 National People's Congress session, the government announced a state-backed venture fund of 1 trillion RMB ($138 billion) to invest in key technology sectors, including AI, quantum computing, renewable energy, and semiconductors.[61] The fund is meant to be a public-private partnership that can emphasize long-term investments and invest higher risk projects.[62] If this investment becomes a reality, it could dwarf all other initiatives across the world.[63]

56. Edd Gent, "Alibaba and Baidu Cash Out on Quantum Computing Stakes, But Tencent and Beijing double down," *IEEE Spectrum*, February 14, 2024, https://spectrum.ieee.org/china-quantum-computer-alibaba-baidu; "Baidu to donate quantum computing lab, equipment to Beijing institute," Reuters, January 3, 2024, https://www.reuters.com/technology/baidu-donate-quantum-computing-lab-equipment-beijing-institute-2024-01-03/.
57. Omaar and Makaryan, "How Innovative Is China In Quantum?"
58. Marc Julienne, "China's Quest for a Quantum Leap," *Reconnect China. Policy Brief* 15 (October 2024), https://www.reconnect-china.ugent.be/wp-content/uploads/2024/10/Reconnect-China_Policy-Brief-15_Chinas-Quest-for-a-Quantum-Leap.pdf.
59. "ASPI's Critical Technology Tracker," Australian Strategic Policy Institute, March 1, 2023, https://www.aspi.org.au/report/critical-technology-tracker.
60. Xu Jing, "China's Hefei builds world-leading high-tech zone," *The Los Angeles Post*, November 28, 2022, https://lapost.us/?p=54856.
61. Byungho Lim, "China Unveils $138 Billion Venture Fund to Boost Quantum, AI, and Clean Energy," *AsiaTechDaily*, March 7, 2025, https://asiatechdaily.com/china-unveils-138-billion-venture-fund-to-boost-quantum-ai-and-clean-energy/.
62. Matt Swayne, "China Launches $138 Billion Government-Backed Venture Fund, Includes Quantum Startups," *Quantum Insider*, March 7, 2025, https://thequantuminsider.com/2025/03/07/china-launches-138-billion-government-backed-venture-fund-includes-quantum-startups/.
63. National Venture Capital Guidance Fund is China's new national-level long-term strategic fund for hard-tech innovation. Learn more: https://baike.baidu.com/en/item/National%20Venture%20Capital%20Guiding%20Fund/1433176 and https://www.chinastrategy.org/2025/12/26/china-launches-venture-capital-fund-to-lead-the-charge-on-tech-investment/.



European Union

As part of its overarching digital transformation strategy—the Digital Decade—the EU aims to be "at the cutting-edge of quantum capabilities by 2030,"[64] and in March 2024, 21 Member States committed to making Europe the 'quantum valley' of the world,[65] by signing the European Declaration on Quantum Technologies.[66]

Major initiatives the EU has rolled out have amounted to nearly €7 billion in public investment in quantum, which ranks the EU second only to China,[67] but some put European public funding to more than 11 billion euros ($13 billion).[68] The EU has been implementing a range of programs and initiatives, from supporting research in quantum computing to deploying a quantum-secure infrastructure.

- In 2018, the European Union initiated the Quantum Flagship, which will invest approximately €1 billion in quantum research over the next decade.[69] It also aims to build up a network of 5,000 quantum-related researchers across the EU.
- In the area of infrastructure, the EU planned to have its first quantum computers by 2025, at six specific sites in the Czech Republic, Germany, Spain, France, Italy, and Poland.[70] This was accomplished through the European High Performance Computing Joint Undertaking (EuroHPC JU), with multiple quantum computers now in use, each with 10 to 140 data qubits.[71]
- Additionally, the European Quantum Communication Infrastructure Initiative (EuroQCI) plans to safeguard sensitive data and critical infrastructure by utilizing quantum communication technologies to build a terrestrial fiber network connecting strategic sites and space-based secure connectivity using satellites (IRIS^2).[72]

The European Commission has also announced a major €65 million investment to drive innovation in quantum chips across the EU Managed by the Chips Joint Undertaking (Chips JU), a European partnership established to strengthen the EU's semiconductor sector, the funding aims to support the development of quantum chips for computing and sensor applications.[73]

Overall, the EU leads in public funding for the quantum sector. Germany recently announced additional investments of $2.25 billion over three years towards the development of a fault-

64. "Quantum," Policies, European Commission, accessed December 21, 2025, https://digital-strategy.ec.europa.eu/en/policies/quantum.
65. "New roadmap to position Europe as the "Quantum Valley" of the world," Quantum Flagship, February 14, 2024, https://qt.eu/news/2024/2024-02-14_new-roadmap-to-position-europe-as-the-quantum-valley-of-the-world.
66. Today there are 26 countries: "European Declaration on Quantum Technologies," Library, European Commission, last modified June 26, 2025, https://digital-strategy.ec.europa.eu/en/library/european-declaration-quantum-technologies.
67. Stefano de Luca, "Quantum: What is it and where does the EU stand?," *European Parliament Directorate-General for Parliamentary Research Services*, accessed December 21, 2025, https://epthinktank.eu/2024/04/10/quantum-what-is-it-and-where-does-the-eu-stand/; "McKinsey Report: Europe Leads in Public Funding for Quantum Tech," HPCwire, June 26, 2024, https://www.hpcwire.com/off-the-wire/mckinsey-report-europe-leads-in-public-funding-for-quantum-tech/.
68. Foo Yun Chee and Milan Strahm, "EU turns to private funding to boost quantum technology ambition," *Reuters*, July 3, 2025, https://www.reuters.com/business/eu-turns-private-funding-boost-quantum-technology-ambition-2025-07-02/.
69. "The future is Quantum," Quantum Flagship, accessed December 21, 2025, https://qt.eu/.
70. "EU Deploys First Quantum Technology in Six Sites Across Europe," News & Views, European Commission, last modified January 30, 2023, https://digital-strategy.ec.europa.eu/en/news/eu-deploys-first-quantum-technology-six-sites-across-europe.
71. "Our Quantum Computers," n.d., https://www.eurohpc-ju.europa.eu/eurohpc-quantum-computers/our-quantum-computers_en.
72. Cierra Choucair, "EU Revives Quantum Communication Investment With $97M To Secure Europe's Infrastructure," *Quantum Insider*, October 23, 2024, https://thequantuminsider.com/2024/10/23/eu-revives-quantum-communication-investment-with-97m-to-secure-europes-infrastructure/.
73. "EU Commission announces €65m funding to advance quantum chips," Innovation News Network, September 25, 2024, https://www.innovationnewsnetwork.com/eu-announces-e65m-funding-to-advance-quantum-chips/51388/; "EU invests €65 million in quantum chips," News & Views, European Commission, September 24, 2024, https://digital-strategy.ec.europa.eu/en/news/eu-invests-eu65-million-quantum-chips.

tolerant quantum computer through its Action Plan for Quantum Technologies, bringing the total to $5.2 billion.[74] France has committed $2.2 billion, the Netherlands $1 billion, Denmark $406 million, Austria $127 million, Spain $67 million, and Finland $27 million.[75]

In 2014, the UK (then still part of the EU) launched the world's first national quantum program. The UK has continued to expand its quantum program. On 5 February 2024, the UK Government announced an investment totaling £45 million as part of a push to transform the UK into a "quantum-enabled economy" by 2033. Furthermore, on 26 July 2024, the Department for Science, Innovation and Technology announced £106 million of government funding for five quantum research hubs. The hubs will be based in Birmingham, Edinburgh, Glasgow, London, and Oxford,[76] and will bring together academia and industry to develop a range of real-world, practical applications across various sectors.[77]

Although the EU appears strong, the reality on the ground is mixed, as the continent exhibits multiple indicators that may predict future challenges. The EU has scattered its efforts across the continent without forming an interconnected quantum ecosystem.[78] Although the Quantum Flagship program is meant to coordinate efforts, most countries still work in silos. Even at the national level, European countries have not achieved the level of coordination between stakeholders and companies that countries such as the U.S. and China have managed.[79] Moreover, after 2021, the technology-led flagship focus of Horizon 2020 was not carried forward to Horizon Europe, which instead was oriented around societal missions. The Quantum Flagship continued, but it seems to have lost some of the prominence it might have enjoyed.[80]

Overall, the EU appears to be creating a private sector with little ability to scale. The European Union is home to 25 percent of all quantum companies worldwide, but accounts for less than 5 percent of global funding.[81] Underinvestment in the industry constrains European companies' ability to develop and grow. European nations lack the private investment that enables quantum computing startups to scale as they do in the U.S., a venture capital powerhouse. Moreover, the EU lacks big digital players that have the power to consolidate the quantum sector. The lack of a European center of gravity to unify the continent's quantum efforts can also be a drawback.

To eliminate these drawbacks, in July 2025 the European Commission launched a new strategy to make Europe a global leader in quantum technology by 2030.[82] The Quantum Europe

74. Steven Vaughan-Nichols, "Nearly Half of Gen AI Adopters Want it Open Source—Here's Why," *Zdnet*, November 21, 2024, https://www.zdnet.com/article/nearly-half-of-gen-ai-adopters-want-it-open-source-heres-why/.
75. Linnea Ahlgren, "Europe is pouring public funds into quantum tech startups, report says," *The Next Web*, June 27, 2024, https://thenextweb.com/news/europe-quantum-public-funding-report.
76. The Quantum Communications Hub at the University of York has spearheaded the development of the UK's first quantum networks, the Hub in Quantum Enhanced Imaging at the University of Glasgow has developed a new imaging technique allowing for precise 3D medical imaging53 and the Quantum Sensors and Timing Hub at the University of Birmingham has designed quantum gradiometers to monitor underground water levels and volcanic eruptions. (Jakob Mokander et al., "A New National Purpose: A UK Quantum Strategy for Sovereignty and Scale," November 2025, https://assets.ctfassets.net/75ila1cntaeh/rYUOhTBdJoHQYIN4YfhFt/caaecccf44c693f61856a8f1c053a351/A_New_National_Purpose_A_UK_Quantum_Strategy_for_Sovereignty_and_Scale.pdf, p. 31)
77. Nigel Howard, Matthew Shapanka, and Tamzin Bond, "Quantum Computing: Developments in the UK and US," *Inside Global Tech*, August 9, 2024, https://www.insideglobaltech.com/2024/08/09/quantum-computing-developments-in-the-uk-and-us/.
78. Keane, "Is quantum computing the next technology on the EU's regulation agenda?"
79. François Candelon, Jean-François Bobier, Maxime Courtaux, and Gabriel Nahas, "Can Europe Catch Up with the US (and China) in Quantum Computing?," *BCG*, August 25, 2022, https://www.bcg.com/publications/2022/can-europe-catch-up-in-quantum-computer-race.
80. David Shaw, "A New Phase for Quantum Competition in Europe," October 7, 2024, A New Phase for Quantum Competition in Europe, https://www.design-reuse-embedded.com/news/202410031/a-new-phase-for-quantum-competition-in-europe/.
81. European Investment Bank and European Commission, *A quantum leap in finance: How to boost Europe's quantum technology industry* (European Investment Bank 2024), https://www.eib.org/attachments/lucalli/20220112_a_quantum_leap_in_finance_en.pdf.
82. Directorate-General for Communication, "The EU's plan to become a global leader in quantum by 2030," *European Commission*, July 2, 2025, https://commission.europa.eu/news-and-media/news/eus-plan-become-global-leader-quantum-2030-2025-07-02_en.

Strategy details a coordinated investment and policy framework to overcome fragmentation, accelerate commercial applications, and secure Europe's technological sovereignty.[83] The strategy addresses research and innovation, quantum infrastructures, industrial ecosystem support, space and dual-use technologies, and quantum skills development. The goal is to adopt a formal European Quantum Act in 2026.[84]



India

Although a major economic actor, India for a long time did not play a prominent role in the development of quantum technology. This is no longer the case. The Indian government has taken an active role in promoting this technology with massive investment in a multilayered network of public and private initiatives that would place India at the forefront of this sector.

The first important step was taken on April 19, 2023. That is when India's government approved a $730 million funding package for the country's National Quantum Mission (NQM).[85] The NQM is a broad national initiative organized around four major objectives: quantum computing, quantum communication, quantum sensing and metrology, and quantum materials and devices. While one component of the mission seeks to develop intermediate-scale quantum computers with 50-1,000 physical qubits by 2031, the initiative encompasses a much wider quantum technology ecosystem.[86] The NQM is organized through four thematic hubs hosted at leading Indian research institutions, with the quantum computing hub housed at the Indian Institute of Science (IISc) in Bengaluru. Contrary to earlier reporting, the mission is not led by the Tata Institute of Fundamental Research (TIFR) in Mumbai. Rather, TIFR leads one of the NQM's 14 working groups in collaboration with IISc, the Indian Institute of Technology Bombay (IITB), and the Indian Institute of Technology Madras (IITM).[87] The mission also seeks to foster collaboration among government laboratories, universities, startups, and private industry to develop quantum technologies and their associated applications.[88] The NQM ultimately aims to cultivate a national ecosystem capable of advancing both strategic and commercial quantum capabilities in India.[89]

To achieve technological self-reliance by 2047, the NQM selected eight startups as part of the first round of funding.[90] One of the government's key objectives is to expand the reach of quantum initiatives beyond metropolitan areas, encouraging participation in smaller towns and rural regions. The initial eight startups are from top technology hubs, including Mumbai, Delhi, and Bengaluru.

83. Matt Swayne, "What's Europe's Quantum Strategy? Breaking Down Europe's Coordinated Plan For Global Quantum Leadership," *Quantum Insider*, July 3, 2025, https://thequantuminsider.com/2025/07/03/whats-europes-quantum-strategy-breaking-down-europes-coordinated-plan-for-global-quantum-leadership/.
84. European Commission, "The EU's plan to become a global leader in quantum by 2030."
85. "Cabinet approves National Quantum Mission to scale-up scientific & industrial R&D for quantum technologies," PIB Delhi, April 19, 2023, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1917888; "National Quantum Mission," Department of Science & Technology of the Ministry of Science & Technology of the Republic of India, https://dst.gov.in/national-quantum-mission-nqm.
86. Stephanie Stacey, "How India became the hottest date in quantum computing," *Tech Monitor*, August 28, 2023, https://www.techmonitor.ai/hardware/quantum/how-india-became-the-hottest-date-in-quantum-computing?cf-view.
87. "India Will Have Its Own Quantum Computer in the Next 3 Years: Dr. Vijay P. Pandurang," IndianWeb2, September 16, 2024, https://www.indianweb2.com/2024/09/india-will-have-its-own-quantum.html#google_vignette.
88. Cierra Choucair, "Quantum Computing In India: Ecosystem Growth & Key Initiatives In 2024," *Quantum Insider*, May 9, 2025, https://thequantuminsider.com/2024/11/27/quantum-computing-advancements-in-india/#Key_Figures_in_Indias_Quantum_Ecosystem.
89. Prateek Tripathi, "Quantum Computing: Current Scenario and Future Prospects," *ORF Issue Brief* 713 (May 2024), https://www.orfonline.org/research/quantum-computing-current-scenario-and-future-prospects.
90. Cierra Choucair, "India Announces Support For Eight Startups Under National Quantum Mission," *Quantum Insider*, November 26, 2024, https://thequantuminsider.com/2024/11/26/india-announces-support-for-eight-startups-under-national-quantum-mission/.

However, initiatives like the one by the state of Andhra Pradesh have partnered with TCS and IBM to create the Amaravati Quantum Computing Center at the Amaravati Quantum Valley.[91] This would become the most extensive quantum computing system to be installed in India. While it would not be entirely an Indian innovation, it will allow TCS and other local innovators to develop algorithms and applications for industry and academia.[92]



Australia

The Australian government has been particularly committed to developing the quantum industry. In May 2023, the government released Australia's first National Quantum Strategy, in which it pledged to invest up to $1 billion from the National Reconstruction Fund.[93] In 2024, these funds were supplemented by $12 million to the University of Sydney to establish a new national center, Quantum Australia, and by $39 million through the Advanced Strategic Capabilities Accelerator for work on emerging and disruptive technologies.[94]

The technology sector is already Australia's third-largest industry, employing one in every 16 workers and contributing $167 billion to the economy each year, or 8.5 percent of GDP. Australian quantum companies have been attracting significant venture capital investment, capturing 3.6 percent of global venture capital for quantum from 2017 to 2021.[95] Industry estimates forecast that revenue from quantum technology could total $5.9 billion by 2045, and the development of quantum technology could contribute $6.1 billion to the Australian economy by the same year.[96] Moreover, this sector could directly employ around 19,400 people, and widespread adoption of quantum technology could create more than 35,000 jobs across the economy by 2045.[97] While these numbers speak for themselves, one of Australia's motivations for such investment is to avoid a repeat of the development of photovoltaic cells, which were invented at the University of New South Wales but were later commercialized by China.[98]

91. Express News Service, "Andhra signs deal to set up India's first Quantum Valley in Amaravati," *The New Indian Express*, May 3, 2025, https://www.newindianexpress.com/states/andhra-pradesh/2025/May/03/andhra-signs-deal-to-set-up-indias-first-quantum-valley-in-amaravati.
92. Pradipta Mukherjee, "Tata, IBM to set up India's largest quantum computer in Andhra Pradesh," *CoinGeek*, May 16, 2025, https://coingeek.com/tata-ibm-to-set-up-india-largest-quantum-computer-in-andhra-pradesh/.
93. "First National Quantum Strategy released," Media Releases, Ministers for the Department of Industry, Science and Resources of the Commonwealth of Australia, May 3, 2023, https://www.minister.industry.gov.au/ministers/husic/media-releases/first-national-quantum-strategy-released.
94. Cierra Choucair, "Australia Invests $39 Million In Quantum And Disruptive Technologies To Strengthen Defense Capabilities," *Quantum Insider*, December 2, 2024, https://thequantuminsider.com/2024/12/02/australia-invests-39-million-in-quantum-and-disruptive-technologies-to-strengthen-defense-capabilities/.
95. Georgia Edmonstone, "Quantum technology: What's in it for Australia?," *United States Studies Centre*, October 23, 2023, https://www.ussc.edu.au/quantum-technology-what-is-in-it-for-australia.
96. Matt Swayne, "Australia's State Of Quantum Update Shares Early Wins, Sets Big Goals, And Sees Big Challenges In Quest Global Quantum Leadership," *Quantum Insider*, November 13, 2024, https://thequantuminsider.com/2024/11/13/australias-state-of-quantum-update-shares-early-wins-sets-big-goals-and-sees-big-challenges-in-quest-global-quantum-leadership/.
97. "Australia's quantum opportunity," Publications, Department of Industry, Science and Resources of the Commonwealth of Australia, accessed December 21, 2025, https://www.industry.gov.au/publications/national-quantum-strategy/australias-quantum-opportunity.
98. Kenji Sato, "Australia signs deal worth almost $1b with PsiQuantum to build world's first 'useful' quantum computer," *ABC news*, April 30, 2024, https://www.abc.net.au/news/2024-04-30/australia-signs-deal-for-first-useful-quantum-computer/103781352.

Moreover, international companies are coming to Australia specifically to capitalize on the country's quantum advantage. Rigetti Computing and Infleqtion, both leading U.S.-based quantum companies, have expanded into Sydney and Melbourne, respectively.[99] Global technology companies have invested in quantum research in Australian universities, including IBM at the University of Melbourne, Microsoft at the University of Sydney,[100] and Google with four Sydney-based universities.

One of the most significant government investments was in U.S.-based PsiQuantum to build the world's first utility-scale fault-tolerant quantum computer in Australia. The investment, totaling almost $1 billion, came from the Queensland and federal governments[101] and made PsiQuantum the world's most-funded independent quantum company.[102]



RECOMMENDATIONS

The United States has already made significant progress in advancing quantum technologies through the National Quantum Initiative Act and related federal programs. Continued investment will remain important to sustain U.S. progress.[103] But the next phase of the national quantum strategy can place greater emphasis on broadening the sources of investment and accelerating the transition from research to deployment.

Specifically, the U.S. can prioritize approaches that leverage public funding to catalyze private-sector participation, including stronger industry partnerships, venture capital engagement, and co-investment models. By bringing in private capital and industry expertise, federal programs can help accelerate commercialization while ensuring that taxpayer resources are used strategically. Taken together, these approaches that include the below would complement existing investments under the National Quantum Initiative while fostering a more balanced ecosystem—combining sustained federal leadership with stronger private-sector participation and clearer pathways to deployment.

- **Catalyze Private Co-Investment.** Structure federal funding to require or incentivize matching private capital (e.g., co-investment funds, milestone-based awards), shifting government's role from primary funder to market catalyst.
- **Accelerate Lab-to-Market Pathways.** Expand late-stage funding mechanisms (e.g., SBIR Phase III, testbeds, pilot deployments) to bridge the gap between research and real-world application.
- **Strengthen Industry Partnerships.** Embed industry more directly into federal quantum programs through consortia, co-development requirements, and talent exchanges to ensure commercial relevance and scalability.
- **Use Procurement as a Strategic Lever.** Modernize acquisition approaches (e.g., OTAs, advance market commitments) to create clear demand signals and viable federal markets for emerging quantum solutions.

99. Edmonstone, "Quantum technology: What's in it for Australia?"
100. However, Microsoft ended its presence in Australia in July 2024 (Denham Sadler, "Microsoft shuts down quantum research in Australia," *ACS Information Age*, July 16, 2024, https://ia.acs.org.au/article/2024/microsoft-shuts-down-quantum-research-in-australia.html).
101. James Purtill, "Australia is making a billion-dollar bet on a 'useful' quantum computer. So what are we buying?," *ABC News*, October 4, 2024, abc.net.au/news/psiquantum-quantum-computer-investment-billion-dollars/104394996.
102. Martijn Boerkamp, "Australia raises eyebrows by splashing A$1bn into US quantum-computing start-up PsiQuantum," *PhysicsWorld*, May 7, 2024, https://physicsworld.com/a/australia-raises-eyebrows-by-splashing-a1bn-into-us-quantum-computing-start-up-psiquantum.
103. Matt Swayne, "Report: China Is Challenging U.S. Leadership In Quantum," *Quantum Insider*, May 9, 2025, https://thequantuminsider.com/2024/09/09/report-china-is-challenging-u-s-leadership-in-quantum/.

INNOVATE

Investment is the first step in creating an infrastructure for technological development in a new sector. Innovation demonstrates whether these resources have been successfully translated into technological advances, scientific breakthroughs, and practical applications. To tell if that investment has borne fruit, it is essential to examine the innovations that have emerged from this effort. The innovation landscape in quantum technologies encompasses multiple dimensions, from fundamental scientific discoveries to applied research breakthroughs, prototype development, and early commercial applications. Understanding this innovation ecosystem requires examining not only the quantity of innovations but also their quality, significance, and potential for real-world impact.

Moreover, because quantum technology encompasses very diverse types of innovation across the three main sectors (sensing, communication, and computing). This means that an exhaustive overview of all innovations would be hard, and comparisons of innovations across sectors would also be difficult to achieve. Instead, this section will focus on the innovation strategy each country has embraced and discuss the most notable achievements.

Innovation patterns also reveal areas of strength and weakness within national quantum programs. Consistent innovation in specific quantum technology areas indicates developed expertise and focused investment, while gaps in innovation suggest either strategic choices to focus resources elsewhere or limitations in research capabilities.

The following sections describe the quantum innovations each country has announced. The length and detail of these sections naturally vary, reflecting differences in research timelines, investment levels, and the current stage of quantum development across different nations.



United States

The private sector is primarily responsible for America's dominance in the quantum computing field, with IBM playing a prominent role. In 2021, IBM developed a 127-qubit chip called Eagle,[104] followed by the 433-qubit Osprey in 2022.[105] On December 4, 2023, it unveiled the first quantum computer, comprising more than 1,000 qubits. The computer is based on a chip called Condor, which has 1,121 superconducting qubits.[106] IBM has been doubling the number of qubits annually, although it has stated its intention to shift its focus to error correction. To this end, IBM invested in its Heron processor, which features the most efficient error correction to date and serves as the foundation for Quantum System Two, IBM's next-generation quantum computing system architecture.[107] To achieve these goals, IBM has announced a new IBM Quantum Data Center in Poughkeepsie to house the world's first large-scale fault-tolerant quantum computer named Starling,[108] which will count as many as 200 logical qubits made up of 10000 physical qubits, making it

104. "IBM Debuts Next-Generation Quantum Processor & IBM Quantum System Two, Extends Roadmap to Advance Era of Quantum Utility," IBM, December 4, 2023, https://newsroom.ibm.com/2023-12-04-IBM-Debuts-Next-Generation-Quantum-Processor-IBM-Quantum-System-Two,-Extends-Roadmap-to-Advance-Era-of-Quantum-Utility.
105. Davide Castelvecchi, "IBM Releases First-ever 1,000-qubit Quantum Chip," *Nature* 624, 238 (2023), https://www.nature.com/articles/d41586-023-03854-1.
106. Castelvecchi, "IBM Releases First-ever 1,000-qubit Quantum Chip."
107. IBM, "IBM Debuts Next-Generation Quantum Processor & IBM Quantum System Two."
108. Nickie Hayes, "IBM reveals Poughkeepsie's role in path toward first fault-tolerant quantum computer," *MSN*, 2025, https://www.msn.com/en-us/news/technology/ibm-reveals-poughkeepsie-s-role-in-path-toward-first-fault-tolerant-quantum-computer/ar-AA1Gquju?ocid=BingNewsVerp.

20000 times more powerful than any quantum computer in existence in 2025.[109] This innovation marks the fact that quantum computers have now entered "an era of utility."[110] This quantum error-correcting code is about 10 times more efficient than prior methods, and the paper introducing it was featured on the cover of *Nature*.[111]

As concrete use cases for these IBM advances, the company has deployed its computers in various facilities. For example, at the Cleveland Clinic, IBM participated in the Discovery Accelerator Center, a quantum-enabled facility dedicated to biomedical research.[112] The IBM Quantum System One computer currently helps screen and optimize drugs targeted to specific proteins, as well as create a quantum-enhanced prediction model for cardiovascular risk following non-cardiac surgery.[113] Another example is the Oak Ridge National Laboratory, funded by DOE, which has access to an IBM Q quantum computer with 85 qubits and up to 6,000 two-qubit gates via the Quantum Computing User Program (QCUP).[114] Breakthroughs at this facility have dealt with critical challenges in materials science and high-energy physics.[115]

One of the significant innovations in this field has been the move to room-temperature quantum computers, which require maintaining the chip at extremely low temperatures to operate correctly. The slightest temperature fluctuation can cause atoms and molecules to move too much, potentially causing a qubit to change its quantum state inadvertently. To this end, temperatures in certain parts of the quantum circuit can be 250 times colder than those in deep space.[116] To address this problem, IBM plans to build a super-fridge named Goldeneye to house its largest quantum computers and conduct future experiments. Goldeneye, despite its large size, requires less space than other large-scale dilution refrigerators to house the same amount of hardware.[117]

Another solution comes from the quantum computing firm PsiQuantum, which is collaborating with the state of Illinois. Because PsiQuantum builds qubits from photons, they can operate at higher temperatures than superconducting systems. While PsiQuantum's computer cannot be operated at room temperature, the superconducting sensors it functions on only need to be cooled to a few degrees Kelvin, or a little under -450 °F. This method is easier to achieve than the cryogenic cooling required for superconducting systems.[118]

109. Tristan Greene, "IBM will build monster 10,000-qubit quantum computer by 2029 after 'solving science' behind fault tolerance—the biggest bottleneck to scaling up," Live Science, June 10, 2025, https://www.livescience.com/technology/computing/ibm-will-build-monster-10-000-qubit-quantum-computer-by-2029-after-solving-science-behind-fault-tolerance.
110. Rafi Letzter, "Landmark IBM error correction paper published on the cover of Nature," *IBM*, March 27, 2024, https://www.ibm.com/quantum/blog/nature-qldpc-error-correction.
111. Sergey Bravyi, Andrew W. Cross, Jay M. Gambetta, Dmitri Maslov, Patrick Rall, and Theodore J. Yoder, "High-threshold and low-overhead fault-tolerant quantum memory," *Nature* 627 (2024): 778-782, https://doi.org/10.1038/s41586-024-07107-7.
112. Margie Graves, "Nation-State Activity in the Age of Artificial Intelligence and Quantum Computing," *IBM Center for the Business of Government*, December 11, 2024, https://businessofgovernment.org/blog/nation-state-activity-age-artificial-intelligence-and-quantum-computing.
113. Paul Smith-Goodson, "Cleveland Clinic And IBM Launch World's First Quantum Computer Dedicated To Healthcare Research And Biomedical Discoveries," *Forbes*, March 21, 2023, https://www.forbes.com/sites/moorinsights/2023/03/21/cleveland-clinic-and-ibm-launch-worlds-first-quantum-computer-dedicated-to-healthcare-research-and-biomedical-discoveries/.
114. Quantum News, "IBM Quantum And Oak Ridge National Laboratory Demonstrate Breakthrough In Ground State Energy Calculation Using New Quantum Algorithm," *Quantum Zeitgeist*, February 25, 2025, https://quantumzeitgeist.com/ibm-quantum-ground-state-energy-calculation-using-new-quantum-algorithm/; Oak Ridge National Laboratory, "Quantum Computing User Program," n.d., https://www.olcf.ornl.gov/olcf-resources/compute-systems/quantum-computing-user-program/.
115. Matt Swayne, "Scientists Simulate Collider Physics On IBM Q Quantum Computer," *Quantum Insider*, April 22, 2024, https://thequantuminsider.com/2022/04/15/scientists-simulate-collider-physics-on-ibm-q-quantum-computer/.
116. Sebastian Moss, "Cooling quantum computers," *Data Centre Dynamics*, January 27, 2021, https://www.datacenterdynamics.com/en/analysis/cooling-quantum-computers/.
117. Pat Guman and Jerry Chow, "IBM scientists cool down the world's largest quantum-ready cryogenic concept system," *IBM*, September 8, 2022. https://www.ibm.com/quantum/blog/goldeneye-cryogenic-concept-system.
118. Sarah Ward, "PsiQuantum plans to build the biggest quantum computing facility in the US," *MIT Technology Review*, July 25, 2024, https://www.technologyreview.com/2024/07/25/1095287/psiquantum-plans-to-build-the-biggest-quantum-computing-facility-in-the-us/.

In on the area of fault tolerance, Google announced a breakthrough in addressing quantum "decoherence" through advanced error correction techniques. By mitigating decoherence, Google's Willow chip enables more stable and reliable quantum computations for longer periods, allowing it to perform a task in roughly 5 minutes that would take the world's largest supercomputer an estimated 10^{25} years.[119]

Microsoft also contributes to this effort with advancements in scalable and fault-tolerant quantum systems. Its Majorana 1 chip aims to build fault tolerance directly into the hardware, significantly improving the feasibility of large-scale quantum computing.[120] Additionally, the partnership with Atom Computing has led to winning a $93 million contract from the Novo Nordisk Foundation and the Export and Investment Fund of Denmark to build *Magne*, a Level 2 quantum computer based on logical qubits, which are more stable and error-resistant than today's physical qubits, and is slated to come online in early 2027.[121] Microsoft will supply the software stack and error correction layer through its recently announced Microsoft Discovery platform, whereas Atom Computing develops quantum hardware using neutral atoms.[122]



China

China dominates the field of quantum communication, roughly matches the U.S. in quantum sensing, and lags in quantum computing.[123] China's long-term plan for quantum communications is to establish a "space-ground integrated quantum secure communication network," comprising a ground-based quantum communication network and a space-based infrastructure. The ground segment began with the completion of the 2,000 km-long "Quantum secure communication Beijing-Shanghai trunk line" in 2016.[124] In recent years, this fiber-optic network has expanded to 10,000 km.[125] The space segment began with the Micius quantum satellite, which was launched into orbit in August 2016. Micius facilitated several experiments in space-to-ground quantum key distribution and ground-to-satellite quantum teleportation.[126] In July 2022, China launched a second quantum satellite named Jinan-1. At roughly the same altitude of 500 km, Jinan-1 is smaller, six times lighter (100 kg), and less expensive than Micius.[127]

119. Davide Castelvecchi, "'A truly remarkable breakthrough': Google's new quantum chip achieves accuracy milestone," *Nature* 636, 527-528 (2024), https://www.nature.com/articles/d41586-024-04028-3; Timothy Papandreou, "Google's Code-Cracking Quantum Leap: Here's What It Means For Business," Forbes, December 16, 2024, https://www.forbes.com/sites/timothypapandreou/2024/12/16/googles-code-cracking-quantum-leap-heres-what-it-mean-for-business/.
120. Dr Ekta Dang, "Recent Breakthroughs Accelerate The Race For Quantum Computing," *Forbes*, March 9, 2025, https://www.forbes.com/sites/drektadang/2025/03/09/recent-breakthroughs-accelerate-the-race-for-quantum-computing/.
121. Charlotte Trueman, "Microsoft and Atom Computing to build "world's most powerful quantum computer" in Denmark," *Data Centre Dynamics*, July 23, 2025, https://www.datacenterdynamics.com/en/news/microsoft-and-atom-computing-to-build-worlds-most-powerful-quantum-computer-in-denmark/.
122. Matt Swayne, "Microsoft And Atom Computing Partner On Level 2 Quantum System For Nordic Users," *Quantum Insider*, July 16, 2025, https://thequantuminsider.com/2025/07/17/microsoft-and-atom-computing-partner-on-level-2-quantum-system-for-nordic-users/.
123. Swayne, "Report: China Is Challenging U.S. Leadership In Quantum."
124. "Chinese Quantum Companies And National Strategy 2023," Quantum Insider, April 21, 2024, https://thequantuminsider.com/2023/04/13/chinese-quantum-companies-and-national-strategy-2023/.
125. Omaar and Makaryan, "How Innovative Is China in Quantum?"
126. Quantum Insider, "Chinese Quantum Companies And National Strategy 2023."
127. Ciel Qi, "China's Quantum Ambitions: A Multi-Decade Focus on Quantum Communications," *Yale Journal of International Affairs*, December 11, 2023, https://www.yalejournal.org/publications/chinas-quantum-ambitions.

In quantum computing, several innovations have been making headlines:

- In 2021, Origin Quantum Computing Technology Co. developed an indigenous quantum computer. China is among a small number of countries developing domestically designed quantum computing systems.[128]
- In May 2023, the Chinese Academy of Sciences (CAS) announced Zuchongzhi, China's largest quantum processor, consisting of 176 qubits.[129] By March 2025, Zuchongzhi 3.0 reached 105 qubits.[130]
- In June 2023, China reported Wukong, a locally-made 72-qubit computer,[131] and later a quantum computing production line, which is now capable of building eight devices simultaneously.[132] In November 2024, Wukong was sold to an overseas client, marking the first time China sold its devices abroad.[133]
- In October 2023, a research team led by Pan Jianwei, China's leading quantum physicist, reported the development of the world's largest photon qubit quantum computer, Jiuzhang 3.0, which had 255 photons.[134]
- In May 2024, scientists reportedly developed Xiaohong, a 504-qubit quantum computing chip that will be made available to researchers worldwide via a new quantum computing cloud platform.[135]
- In June 2025, China announced the unveiling of Hanyuan-1, the country's first room-temperature neutral-atom quantum computer. This 100-qubit system entered commercial use in November when it was sold to China Mobile, with another unit scheduled for export to Pakistan, one of the first international sales of a Chinese quantum computer.[136]

A closer examination revealed that the Chinese research has shown significant progress in exploiting cryptographic weaknesses through specialized quantum techniques, but it has not demonstrated full-fledged universal quantum decryption.[137] These systems represent important advances in specialized or experimental architectures but do not yet constitute general-purpose, fault-tolerant quantum computers comparable to leading commercial platforms in the U.S.

China has the financial and human capital to continue sustained investment in quantum. Some worry that the recent example of the Chinese firm DeepSeek's R1 model competing with large language models (LLMs) dominated by American firms such could be replicated in the quan-

128. Staff Reporters, "'Origin Wukong' Ushers in China's Quantum Computing Era," *Science and Technology Daily*, May 14, 2024, https://www.stdaily.com/web/English/2024-05/14/content_1960339.html.
129. Brian Hart, Bonny Lin, Samantha Lu, Hannah Price, Yu-jie (Grace) Liao, Matthew Slade, "Is China a Leader in Quantum Technologies?," *China Power*, last modified January 31, 2024, https://chinapower.csis.org/china-quantum-technology/.
130. "China hits new landmark in global quantum computing race," CGTN, March 4, 2025, https://news.cgtn.com/news/2025-03-04/China-hits-new-landmark-in-global-quantum-computing-race-1BsCvFWWvp6/p.html.
131. Jeff Pao, "China's fastest yet quantum computer still way behind US," *Asia Times*, June 9, 2023, https://asiatimes.com/2023/06/chinas-fastest-yet-quantum-computer-still-way-behind-us/.
132. Matt Swayne, "China Expands Quantum Computing Production Line, Can Now Build 8 Devices At Once," *Quantum Insider*, October 8, 2024, https://thequantuminsider.com/2024/10/08/china-expands-quantum-computing-production-line-can-now-build-8-devices-at-once/.
133. Chang Chaofan, "Chinese superconducting quantum computing power sold to overseas client," *Global Times*, November 4, 2024, https://www.globaltimes.cn/page/202411/1322416.shtml; Li Yan, "China's self-developed superconducting quantum computer completes 270,000 tasks," *ECNS*, November 4, 2024, https://www.ecns.cn/m/news/cns-wire/2024-11-05/detail-iheitrxu8654737.shtml.
134. Deng, "China secures world-leading computational power."
135. Owen Hughes, "China creates its largest ever quantum computing chip—and it could be key to building the nation's own 'quantum cloud'," *Live Science*, May 13, 2024 https://www.livescience.com/technology/computing/china-creates-its-largest-ever-quantum-chip-and-it-could-be-key-to-building-the-nations-own-quantum-cloud.
136. Marin Ivezic, "China Deploys 100-Qubit Neutral-Atom Quantum Computer," *PostQuantum*, November 1, 2025, https://postquantum.com/industry-news/china-100-qubit/.
137. Micah McCartney, "China's Quantum Computer Scientists Crack Military-Grade Encryption," *Newsweek*, last modified October 23, 2024, https://www.newsweek.com/china-news-quantum-computer-scientists-crack-military-grade-encryption-1970760.

tum technology field.[138] While DeepSeek was a small start-up,[139] many of the quantum actors in China have been consolidating into large entities under government control. This means that AI and quantum might take different paths in China.



European Union

Europe is already a producer of quantum computers, with companies such as IQM, Quandela, Pasqal, and AQT, as well as more than 120 startups.[140] Europe has also taken the lead in several key technologies essential for quantum computing. These include:

- Cryogenics: The Finnish company Bluefors is the clear worldwide leader in cryogenic systems used for quantum computing, with over 70 percent of the market share.
- Special cables: These are needed to perform input and output operations between qubits and traditional electronics without upsetting the extremely cold environments the qubits need to operate in. Dutch producers lead the field in this area.
- Connectors: French firm Radiall sells magnetically shielded connectors, miniature connectors, and cryo switches for use in quantum systems.[141]

The European quantum sector primarily consists of smaller ecosystems in the five member states that have formulated comprehensive national quantum technology strategies: Denmark, France, Germany, Ireland, and the Netherlands.

- In the Paris Region of France (Région Ile-de-France), GENCI, in conjunction with Le Lab Quantique, a nonprofit organization promoting quantum computing, has created the PAck Quantique (PAQ) initiative.[142] PAQ funds projects tackling significant industrial challenges by partnering startups with academic consortia. In 2020, this three-year program funded three real-world use-case projects in the energy (EDF, Total) and pharmacology (Qubit Pharmaceuticals) sectors.
- The second initiative in France is the Teratec Quantum Computing Initiative (TQCI), which aims to foster complementarities between academia and industry to rapidly build up skills and develop know-how in the field of quantum computing, bringing together future users, technology providers, and research centers.[143]
- In Finland, a collaborative project between VTT Technical Research Centre and the Finnish start-up IQM developed a 50-qubit quantum computer.[144]

138. Carter C. Price and Brien Alkire, "What DeepSeek Means for AI Competition: The Beginning of the End or the End of the Beginning," *RAND*, February 24, 2025, https://www.rand.org/pubs/commentary/2025/02/what-deepseek-means-for-ai-competition-the-beginning.html.
139. Tom Wheeler, "DeepSeek is not a good reason for Big Tech to become more powerful," *Brookings*, February 11, 2025, https://www.brookings.edu/articles/deepseek-ai-big-tech-competition/.
140. Martin Greenacre, "European industry is yet to embrace the potential of quantum technologies," *Science|Business*, March 26, 2024, https://sciencebusiness.net/news/quantum-computing/european-industry-yet-embrace-potential-quantum-technologies.
141. Pat Brans, "Europe carves out niche in quantum computing," *Computer Weekly*, February 9, 2024, https://www.computerweekly.com/news/366569217/Europe-carves-out-niche-in-quantum-computing.
142. "Le PAck Quantique: An innovative program to support quantum computing in the Paris Region," GENCI, November 25, 2020, https://www.genci.fr/en/news/le-pack-quantique-innovative-program-support-quantum-computing-paris-region.
143. Mikael P. Johansson, Ezhilmathi Krishnasamy, Norbert Meyer, and Christelle Piechurski, *Quantum Computing—A European Perspective* (Partnership for Advanced Computing in Europe, 2021), https://zenodo.org/records/5547408/files/TR-Quantum-Computing-2021-09-23b.pdf?download=1.
144. "Finland launches Europe's first 50-qubit quantum computer," Innovation News Network, March 4, 2025, https://www.innovation-newsnetwork.com/finland-launches-europes-first-50-qubit-quantum-computer/56055/.

- In Germany, the Quantum Technology and Application Consortium (QUTAC), comprises ten of the most influential German companies, which will utilize their resources and expertise to accelerate German innovation in the field of quantum computing.
- Additionally, Germany developed the world's first room-temperature quantum computer.[145] While the synthetic diamond chip of this computer can only handle 5 qubits, the fact that it does not require any cooling infrastructure means that it can work alongside classical computers and can be more easily integrated into existing systems, making it cheaper to build, own, and run, thus bringing quantum technology closer to end users.
- The Netherlands has also begun a quantum computing initiative, Quantum Delta NL, which has already allocated €615 million in funding. The Quantum Delta NL is a private-public partnership responsible for organizing the implementation of quantum projects outlined in the Netherlands' National Agenda for Quantum Technology (NAQT). The funding will be dedicated to training 2,000 researchers, hosting three commercial R&D infrastructures by 2027, and supporting up to 100 start-up companies.[146]
- Poland has entered the race with a 5-qubit IQM quantum computer at Wroclaw University of Science and Technology. It uses low-temperature, superconducting qubit technology, and it is outstanding because it is meant for direct access by students and companies, when most university-level quantum programs rely heavily on simulation environments or limited-time access to cloud-based systems.[147]
- Poland has also integrated quantum technologies into medtech, where the company Quantum Innovations developed the world's first sensor technology for monitoring organs during surgery and for transplantation, enabling real-time ECG monitoring directly from the surface of a beating heart and tracking tissue metabolism during surgery.[148]
- In 2014, the UK (then still part of the EU) launched the world's first national quantum program. The country boasts four universities in the world's top 10, all with leading quantum technology research activities, and the UK quantum program, now over a decade old, is the world's most mature and a great success. London, though facing its own challenges, remains Europe's most credible and deepest capital market. After Brexit the country was excluded from the Horizon Europe program, though was later reincluded.[149]

These companies excel in niche areas, such as silicon quantum computing,[150] lasers, and cryogenic technology, but require coordinated support to scale globally. The EU cannot nurture these niches because it lacks a comprehensive quantum strategy, which limits informed decision-making.[151] Moreover, some complaints address the significant red tape that hinders progress for European companies.[152] The EU has been working diligently to address these

145. Flaherty, "First room-temperature quantum computer in supercomputing centre."
146. Johansson et al., *Quantum Computing—A European Perspective*.
147. Lucy Adams, "Poland installs its first superconducting quantum computer," *tech.eu*, April 24, 2025, https://tech.eu/2025/04/24/poland-installs-its-first-superconducting-quantum-computer/.
148. Stefano De Marzo, "Warsaw-based Quantum Innovations raises €9.4 million to develop cardiac surgery monitoring tech," *EU-Startups*, June 20, 2024, https://www.eu-startups.com/2024/06/warsaw-based-quantum-innovations-raises-e9-4-million-to-develop-cardiac-surgery-monitoring-tech/.
149. "UK secures greater access to Horizon Europe funding for space and quantum tech," Innovation News Network, April 29, 2025, https://www.innovationnewsnetwork.com/uk-secures-horizon-europe-funding-for-space-and-quantum-tech/57583/.
150. Kaif Shaikh, "Powerful ion beam to enrich ultra-pure silicon for quantum computing," *Interesting Engineering*, January 10, 2025, https://interestingengineering.com/innovation/europe-funds-silicon-for-quantum-computing; Matt Swayne, "Equal1 And The Irish Centre For High-End Computing Sign Agreement To Advance Quantum Innovation In Ireland And Europe," *Quantum Insider*, June 25, 2024, https://thequantuminsider.com/2024/06/24/equal1-and-the-irish-centre-for-high-end-computing-sign-agreement-to-advance-quantum-innovation-in-ireland-and-europe/.
151. Herman Quarles van Ufford, "From niche innovations to global powerhouse: An EU quantum strategy," *European Council on Foreign Relations*, December 20, 2024, https://ecfr.eu/article/from-niche-innovations-to-global-powerhouse-an-eu-quantum-strategy/.
152. Jennifer Baker, "Quantum needs more investment, better innovation recipe for growth," *Euractiv*, last modified October 1, 2024, https://www.euractiv.com/section/tech/news/quantum-needs-more-investment-better-innovation-recipe-for-growth/.

challenges and is now developing the Quantum Europe Strategy. Among the planned innovations in communications, the EuroQCI initiative aims to build a secure quantum network spanning all European countries, utilizing both terrestrial fiber and satellite links, with the first space-based quantum key distribution satellite, Eagle 1, scheduled for launch in 2026.[153]



India

In the United States, IBM has already demonstrated a functioning quantum processor exceeding 1,000 qubits through its 1,121-qubit Condor system.[154] By comparison, Indian researchers from DRDO, TIFR, and TCS successfully tested a 6-qubit superconducting quantum processor in 2024, representing an early but important milestone in India's broader quantum computing development effort.[155] The country—while still innovating compared to those without quantum ambitions—is only now laying the groundwork for future breakthroughs.

Among recent advances, India has made significant strides in quantum communication.

- For example, scientists at IIT Delhi, working in collaboration with India's Defense Research and Development Organization (DRDO), successfully transmitted secure messages using quantum entanglement over a distance of more than one kilometer.[156]
- A team at the Indian Institute of Science (IISc) has experimentally demonstrated universal quantum gates by encoding three qubits in a single photon, and then entangled two such photons to form a 6-qubit system, showing that photonic qubits can deterministically implement multi-qubit gates at room temperature.[157]
- The Center for Development of Telematics (C-DOT) is collaborating with Synergy Quantum India, a leading deep-tech firm specializing in quantum technologies, to develop drone-based Quantum Key Distribution (QKD) systems.[158]
- A significant amount of innovation is expected to come from international collaborations, such as the Andhra Pradesh Quantum Valley Tech Park, which will house an IBM Quantum System Two featuring a 156-qubit Heron processor.[159] Rigetti Computing has followed this collaborative trend with an initiative to co-develop hybrid quantum computing systems with the Centre for Development of Advanced Computing (C-DAC).[160]

153. Swayne, "What's Europe's Quantum Strategy?"
154. IBM, "IBM Quantum Roadmap," IBM Quantum, accessed May 11, 2026.
155. Sibu Kumar Tripathi, "DRDO, TIFR test 6-qubit quantum processor: What it means for India's quantum future," *India Today*, September 1, 2024, https://www.indiatoday.in/science/story/drdo-tifr-test-6-qubit-quantum-processor-what-it-means-for-indias-quantum-future-2591688-2024-09-01.
156. Girish Linganna, "Quantum breakthrough: India cracks the code to unbreakable messaging," *Mathrubhumi*, June 17, 2025, https://english.mathrubhumi.com/features/science/quantum-breakthrough-india-cracks-the-code-to-unhackable-messaging-trbfmdgf.
157. Kanad Sengupta, S. P. Dinesh, K. Muhammed Shafi, K. Muhammed, Soumya Asokan, and C. M. Chandrashekar, "Experimental realization of universal quantum gates and a six-qubit entangled state using a photonic quantum walk," *Physical Review Applied* 24, no. 2 (2025): 12-24, https://journals.aps.org/prapplied/abstract/10.1103/r7yp-1vz4.
158. Cierra Choucair, "India To Advance Drone-Based Quantum Security With C-DOT And Synergy Quantum Partnership," *Quantum Insider*, May 12, 2025, https://thequantuminsider.com/2025/05/12/india-to-advance-drone-based-quantum-security-with-c-dot-and-synergy-quantum-partnership/.
159. The New Indian Express, "Andhra signs deal to set up India's first Quantum Valley in Amaravati."
160. GlobeNewswire, "Rigetti and India's Centre for Development of Advanced Computing Announce MOU to Explore Co-Development of Hybrid Quantum Computing Systems," *Business Insider*, September 2, 2025, https://markets.businessinsider.com/news/stocks/rigetti-and-india-s-centre-for-development-of-advanced-computing-announce-mou-to-explore-co-development-of-hybrid-quantum-computing-systems-1035105969.



Australia

There are currently over 10 Australian-based quantum technology startups, many spun out from universities. The most famous are Diraq, Silicon Quantum, and Q-CTRL. Diraq is a startup led by Andrew Dzurak from the University of New South Wales.[161] Silicon Quantum Computing was founded by Michelle Simmons, who is also at the University of New South Wales. She recently raised $50 million to manufacture the world's first scalable, error-corrected quantum computer.[162] Their "AI accelerator for quantum machine learning" was initially planned for a 2028 release, but it has already begun customer testing and could be released in 2026.[163] Q-CTRL has focused on a commercially viable quantum navigation system that operates without the Global Positioning System (GPS) and therefore cannot be jammed, and is significantly more accurate.[164]

Additional Australian innovations stand out:

- The University of Wollongong (UOW) developed a project aimed at improving diagnosis and treatment for cancer using state-of-the-art quantum photon-counting detectors.[165]
- Quantum sensing startup DeteQt, spun out of the University of Sydney Nano Institute, has patented "diamond-on-silicon" quantum magnetometers, which have potential applications in GPS-denied navigation, critical mineral detection, and portable medical imaging.[166]
- The use of diamonds in quantum computing led to breakthroughs by Australian startup Quantum Brilliance. They opened the world's first commercial quantum diamond foundry in Melbourne, which will help build lab-grown diamonds into computer circuits to make quantum devices smaller, portable, and able to function at room temperature.[167]
- CSIRO developed LandTEM to detect very weak magnetic fields using quantum sensors. This technology has helped discover more than $10 billion in ore deposits worldwide, with $4 billion of these discoveries in Australia.[168]

161. John Davidson, "Start-up says it will beat famous Aussie rival to make a quantum computer," *Australian Financial Review*, February 20, 2024, https://www.afr.com/technology/start-up-says-it-will-have-a-quantum-computer-by-2028-20240219-p5f64k.
162. Purtill, "Australia is making a billion-dollar bet on a 'useful' quantum computer."
163. Mark Whittaker, "Look out, here comes a quantum AI accelerator," *Forbes*, July 7, 2024, https://www.forbes.com.au/covers/innovation/look-out-here-comes-a-quantum-ai-accelerator/.
164. Christopher McFadden, "Australia unveils jam-proof quantum tech that's 50 times more accurate than GPS," *Interesting Engineering*, April 15, 2025, https://interestingengineering.com/innovation/australia-firm-gps-less-navigation-system.
165. Yogesh Bhatia, "Quantum technology to transform medical imaging and cancer treatment," *University of Wollongong Australia*, November 27, 2024, https://www.uow.edu.au/media/2024/quantum-technology-to-transform-medical-imaging-and-cancer-treatment.php.
166. Kate B., "University of Sydney spin-out DeteQt lands $750K for quantum sensing innovation," *Australian Manufacturing*, March 25, 2025, https://www.australianmanufacturing.com.au/university-of-sydney-spin-out-deteqt-lands-750k-for-quantum-sensing-innovation/.
167. Charlotte Trueman, "Quantum Brilliance opens commercial quantum diamond foundry in Melbourne, Australia," *Data Centre Dynamics*, November 6, 2025, https://www.datacenterdynamics.com/en/news/quantum-brilliance-opens-commercial-quantum-diamond-foundry-in-melbourne-australia/.
168. "Success stories for quantum in Australia," News, Department of Industry, Science and Resources of the Commonwealth of Australia, April 14, 2024, https://www.industry.gov.au/news/success-stories-quantum-australia.

RECOMMENDATIONS

News about the latest advances in quantum technology often makes headlines. This seemingly relentless pace of innovation reflects a global environment in which technological leadership directly translates into economic advantage and national security capability. The U.S. currently leads in this quantum revolution, and this leadership rests on decades of sustained investment in fundamental research that created the scientific foundation enabling today's breakthroughs. This research-to-innovation pipeline represents one of America's most valuable strategic assets, converting scientific curiosity into technological supremacy. However, other nations are moving forward in innovation. At a time of increased government efficiency, investment in basic research remains crucial. The U.S. has made significant advances thanks to academic research, and this remains critical for future innovation. The quantum research ecosystem presents a compelling case for strategic investment. Research innovation strategies can follow several paths. The U.S. can continue its preeminent role in innovation in several ways:

- **Continue investment in innovation**. The economic returns from quantum technologies promise to generate value that far exceeds research investments, while the national security implications of quantum capabilities make continued leadership imperative rather than optional.
- **Investing in strengths**. This strategy can help ensure strength in selective sectors. For example, the U.S. leads in quantum computing, and continued investment in this sector can ensure sustained performance.
- **Investing in new initiatives**. Directing investments into new areas can create strengths that might not currently be on anyone's radar. Funding through prize challenges can widely reward innovation by harnessing creativity to uncover what has not yet been discovered.[169]

EDUCATE

Because quantum computers operate on a completely different paradigm from classical computing, both in terms of hardware and software, the expertise required to create working products that leverage this innovation presents a significant challenge. Currently, only a small, highly skilled elite workforce possesses the necessary knowledge to work in this field. In 2021, there was only one qualified candidate for every three quantum jobs available,[170] and the gap continues to persist.[171]

169. As an example, the National Center for Advancing Translational Sciences (NCATS), part of the National Institutes of Health (NIH), announced the NIH Quantum Sensing Technology Challenge, one of two parallel Prize Challenges for the NIH Quantum Biomedical Innovations and Technologies (Qu-BIT) Program. It targeted multi-disciplinary collaborative teams to propose and develop new biomedical use cases of existing quantum-enabled technologies and to adapt and optimize them for use in biomedical research and clinical settings (https://www.quantum.gov/nih-webinars-on-quantum-technology-prize-challenges/)
170. Mateusz Masiowski, Niko Mohr, Henning Soller, and Matija Zesko, "Quantum computing funding remains strong, but talent gap raises concern," *McKinsey*, June 15, 2022, https://www.mckinsey.com/capabilities/tech-and-ai/our-insights/quantum-computing-funding-remains-strong-but-talent-gap-raises-concern#/.
171. Niki Mohr, Kiera Peltz, Rodney Zemmel, and Matija Zesko, "Five lessons from AI on closing quantum's talent gap—before it's too late," *McKinsey*, December 1, 2022, https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/five-lessons-from-ai-on-closing-quantums-talent-gap-before-its-too-late.

An April 2025 report found that only 29 out of 176 university quantum programs worldwide offer a graduate degree in quantum computing, but new academic paths are emerging.[172] Many suggest investing more in foundational STEM education at an early age to address workforce limitations and democratize access to these powerful systems.[173] Another approach has been to develop ready-to-run quantum software that allows subject matter experts with no prior quantum experience to use it in hybrid classical-quantum computing systems.[174]

Competition is fierce, with multiple sectors and governments vying for the same small pool of experts—leading to bidding wars and rising salaries. For certain niche roles (e.g., quantum hardware engineers or cryogenics specialists), qualified candidates are extremely scarce.[175] Moreover, the training required to develop quantum algorithms will be significantly different from that needed to develop quantum hardware.[176]

Although there are not enough doctoral-level quantum specialists in the job market, many engineers and developers are eager to learn more about this field.[177] Nonprofits and companies have also stepped in. The Coding School's Qubit by Qubit initiative has already trained over 22,500 students and professionals in quantum computing across 130 countries.[178] Major quantum firms are offering training programs to fill this gap. D-Wave, for instance, saw an 85 percent jump in enrollments for its quantum programming courses in early 2024.[179] Meanwhile, corporate-academic collaborations are creating talent pipelines through internships and joint research. SandboxAQ, for example, has partnered with over 30 universities to co-train graduate students and upskill corporate employees on real-world quantum projects.[180]

The rapid expansion of quantum academic programs creates quality concerns. Universities face critical shortages of qualified faculty with deep quantum expertise. This raises the risk that scale expansion may outpace instructional depth, producing graduates with superficial rather than sophisticated quantum knowledge. Additionally, growing restrictions on international academic mobility threaten to disrupt the cross-border collaboration that has historically driven quantum research breakthroughs. These constraints on researcher exchanges and collaborative partnerships may affect long-term research quality, as scientific progress depends on the free exchange of ideas and diverse perspectives that international collaboration enables.

172. Yuval Boger, "How to Solve the Talent Crunch Facing Quantum Tech," *Builtin*, April 1, 2025, https://builtin.com/articles/build-quantum-tech-workforce.
173. Guido Peterssen, "Quantum Technology Impact: The Necessary Workforce for Developing Quantum Software," *QANSWER* (2020): 6-22, https://ceur-ws.org/Vol-2561/paper1.pdf.
174. Julian van Velzen, "The Future Of Quantum Computing Requires An Emerging Quantum Workforce," *Forbes*, March 1, 2023, https://www.forbes.com/sites/forbestechcouncil/2023/03/01/the-future-of-quantum-computing-requires-an-emerging-quantum-workforce/?sh=5037145c4239.
175. Boger, "How to Solve the Talent Crunch Facing Quantum Tech."
176. Kenna Hughes-Castleberry, "Help Wanted: How To Build A Diverse Quantum Workforce," *Quantum Insider*, April 22, 2024, https://thequantuminsider.com/2021/09/22/help-wanted-how-to-build-a-diverse-quantum-workforce/.
177. Cierra Choucair, "Building The Quantum Workforce Through Diverse Education And A Collective Push," *Quantum Insider*, December 28, 2024, https://thequantuminsider.com/2024/12/28/building-the-quantum-workforce-through-diverse-education-and-a-collective-push/.
178. The author of this report took this year-long coding course in the 2022-23 academic year.
179. "D-Wave Quantum Inc. (NYSE: QBTS) Sees Double Digit Growth in 1H 2024 Training Enrollments with Workforce Development Initiative," StreetInsider, August 13, 2024, https://www.streetinsider.com/Investor+Brand+Network/D-Wave+Quantum+Inc.+%28NYSE%3A+QBTS%29+Sees+Double+Digit+Growth+in+1H+2024+Training+Enrollments+with+Workforce+Development+Initiative/23592375.html#:~:text=,Wave%20training%20course%20recommend%20it.
180. "SandboxAQ Collaborates with More Than 30 Universities, Corporations and Other Educational Organizations to Expand AI, Quantum Education and Upskill Workers," Press Releases, SandboxAQ, August 15, 2023, https://www.sandboxaq.com/press/sandboxaq-collaborates-with-universities-corporations-and-other-educational-organizations-to-expand-ai-quantum-education.



United States

Under the National Quantum Initiative Act of 2018, the United States has already allocated substantial funding to develop a quantum workforce.[181] Among the points of this action plan are objectives such as:

- Encouraging the creation of collaborations between industry and academic institutions
- Using and improving existing programs to increase the quantum workforce
- Encouraging educational institutions to consider quantum science and engineering as a different discipline in need of new teachers, curricula, and initiatives
- Starting quantum science education as early as primary school
- Targeting the wider public so that quantum science knowledge increases at the level of the whole society[182]

In 2022, there were no bachelor's degree programs in quantum engineering in the United States, and only a handful of PhD programs. Many institutions were adding tracks within majors or one-off courses in quantum technology (the University of Maryland, for example, has launched a professional certificate in quantum computing for non-specialists).[183]

- MIT has also developed an online two-course professional certificate program that explores the business and technical implications of quantum computing.[184]
- Miami University approved Ohio's first Bachelor of Science in Quantum Computing, set to start in August 2025, pending approval. This 88-credit-hour program, housed in the College of Engineering and Computing, was developed in collaboration with the Cleveland Clinic.[185]
- IBM announced an intent to engage with Keio University, the University of Tokyo, Yonsei University, Seoul National University, and the University of Chicago, with a plan to train up to 40,000 students over the next 10 years.[186] IBM expanded its collaboration in Illinois on the new National Quantum Algorithm Center in the Illinois Quantum and Microelectronics Park (IQMP) in Chicago. Both the University of Chicago and the University of Illinois Urbana-Champaign are included in the initiative, and the center will be fueled by IBM Quantum System Two, utilizing IBM Quantum Heron.[187]
- Microsoft offers free quantum learning platforms like the Quantum Development Kit and the Azure Quantum open cloud ecosystem.[188]

However, only 53 percent of U.S. high schools offer foundational computer science classes, and only 27 of the 50 states and the District of Columbia require all high schools to offer

181. The NQI is effort is undergoing a push for reauthorization in 2025 (Matt Swayne, "U.S. Quantum Industry Leaders Press Congress To Expand Support," *Quantum Insider*, May 8, 2025, https://thequantuminsider.com/2025/05/08/u-s-quantum-industry-leaders-press-congress-to-expand-u-s-support/#:~:text=At%20a%20May%207%20House%20Science%20Committee%20hearing%2C,Initiative%20to%20maintain%20U.S.%20leadership%20in%20quantum%20technologies).
182. Peterssen, "Quantum," p. 14.
183. Meredith Fore, "The Newest Quantum Frontier: Building a Skilled Workforce," *APS News*, August 8, 2022, https://www.aps.org/apsnews/2022/08/quantum-education.
184. Choucair, "Building The Quantum Workforce."
185. Sean Scott, "Miami University plans to create new quantum computing major," *Journal-News*, December 28, 2024, https://www.journal-news.com/business/miami-university-plans-to-create-new-quantum-computing-major/ESO7NMBXYNCS7J5EPJHCBGRXPY/.
186. "IBM and Top Universities to Advance Quantum Education for 40,000 Students in Japan, South Korea, and the United States," IBM, December 13, 2023, https://newsroom.ibm.com/2023-12-13-IBM-and-Top-Universities-to-Advance-Quantum-Education-for-40,000-Students-in-Japan,-South-Korea,-and-the-United-States.
187. "IBM and State of Illinois to Build National Quantum Algorithm Center in Chicago with Universities and Industries," IBM, December 12, 2024, https://newsroom.ibm.com/2024-12-12-ibm-and-state-of-illinois-to-build-national-quantum-algorithm-center-in-chicago-with-universities-and-industries.
188. Choucair, "Building The Quantum Workforce."

computer science.[189] There have been initiatives in Ohio, California, and Colorado, but a federal model may be a more effective approach to expanding quantum science knowledge among the U.S. public.[190]

However, education alone will not be enough to address the U.S. quantum talent gaps, as many graduates of quantum programs in the U.S. are on education visas, which require them to leave the country upon completion of their degrees.[191]



China

The government has invested in developing an extensive training program for quantum experts. This is visible in the quantum research that the country has been producing. Between 2011 and 2020, China published more than 14,000 publications on quantum technology.[192] Between 2018 and 2022, China ranked first globally in publications on quantum communication, with the U.S. in second place. However, China lags slightly behind in quantum sensing research and is even further behind in quantum computing research, with the United States ranked highest in both these fields.[193]

In training future quantum specialists, China has more than 100 universities and national laboratories that publish significant amounts of public research across all areas of quantum science.[194] As of 2023, the country hosted 12 dedicated quantum technology research institutions and had the third-largest number of graduates in quantum computing.[195] Recent moves are aimed at solidifying this direction.

In 2024, approximately 100 traditional majors were removed or suspended in favor of emerging disciplines, including quantum computing. Between 2013 and 2022, the number of engineering majors at universities nationwide increased by 7,566, with 96 new areas of study introduced, including robotics, AI, and big data. Meanwhile, traditional engineering disciplines were being phased out in favor of majors that align with China's future industrial needs, such as blockchain, integrated circuit design, and cybersecurity.[196]

This approach can create massive shifts quickly, but it can also cause significant dislocations as the majors being phased out are phased out overnight, while attempting to hire competent teachers for the new programs. Just because the Chinese government decides to create new quantum computing majors doesn't mean professors who can teach across a wide array of quantum topics will be readily available or able to teach at a high level.

189. Pat Yongpradit, Hannah Weissman, and Veronica Ellis, *2025 State of AI + CS Education* (Code.org 2025), https://advocacy.code.org/stateofcs.
190. Brandon Kirk Williams, "The U.S. Needs a Strategy for the Second Quantum Revolution," *Lawfare*, May 3, 2024, https://www.lawfaremedia.org/article/the-u.s.-needs-a-strategy-for-the-second-quantum-revolution.
191. Hodan Omaar, *The U.S. Approach to Quantum Policy* (Center for Data Innovation 2023), https://www2.datainnovation.org/2023-us-quantum-policy.pdf.
192. It measures the total number of research papers published and the number of citations received.
193. Omaar and Makaryan, "How Innovative Is China in Quantum?"
194. Edward Parker, *The Chinese Industrial Base and Military Deployment of Quantum Technology* (RAND 2024), https://www.rand.org/pubs/testimonies/CTA3189-1.html.
195. Tripathi, "Quantum Computing: Current Scenario and Future Prospects."
196. Matt Swayne, "China Reshaping Higher Education With Focus On Quantum, Deep Tech Workforce," *Quantum Insider*, August 31, 2024, https://thequantuminsider.com/2024/08/31/china-reshaping-higher-education-with-focus-on-quantum-deep-tech-workforce/.



European Union

The European quantum ecosystem is globally strong, largely due to the contributions of academic researchers and startups. The key to Europe's future competitiveness lies in its ability to enable research institutions and industries to leverage these new quantum solutions to address real-world problems. When it comes to quantum computing, Europe is already well-positioned in key areas, including publicly funded research and academia, a dynamic industrial ecosystem, leadership in enabling technologies, the integration of high-performance computers and quantum systems, and responsible innovation.[197]

Startups focused on quantum computing often find themselves at the intersection of academic research and marketability, often with academic backgrounds.[198] The EU has the highest number and concentration of quantum talent, producing over 110000 STEM graduates every year.[199] However, the quantum sector faces acute labor shortages, especially in applied areas like software engineering, systems integration, and cybersecurity. The European Commission is addressing these shortcomings by launching a European Quantum Skills Academy in 2026. It will offer training modules, fellowship schemes, and virtual teaching resources, while aiming to address diversity and the gender gap in the sector.[200]

Education and training initiatives will undoubtedly be at the top of the policy agenda. Some programs are already up and running, including the QTIndu Project, which aims to develop a pan-European short-term training program in quantum technology specifically tailored to the requirements of companies and SMEs from across various business sectors.[201]

The UK has emerged with several important initiatives.

- The University of Sussex started an online Quantum Technology Applications and Management MSc for professionals who want to commercialize this technology.[202]
- Researchers from Quantinuum, the University of Oxford, and University College London have launched a pilot program of Quantum Picturalism (QPic) to teach quantum principles using diagram-based instruction to people without prior knowledge of advanced mathematics.[203] This approach has already been used in university courses across Oxford, Amsterdam, and Cambridge, as well as at Indiana University, and in programs at Google and Quantinuum, for tasks such as quantum circuit optimization.[204]

197. Brans, "Europe carves out niche in quantum computing."
198. Johansson, Krishnasamy, Meyer, and Piechurski, *Quantum Computing—A European Perspective*.
199. Niko Mohr et al., *Quantum Technology Monitor* (McKinsey Digital 2024), 42, https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/steady%20progress%20in%20approaching%20the%20quantum%20advantage/quantum-technology-monitor-april-2024.pdf.
200. Swayne, "What's Europe's Quantum Strategy?".
201. Baker, "Quantum needs more investment."
202. Choucair, "Building The Quantum Workforce."
203. Classes in quantum mechanics are typically reserved for university students with advanced training in mathematics, as the standard method of teaching requires fluency in vectors, matrices, complex numbers, and linear algebra. This approach often leaves out most high school students, as well as many professionals who took math decades ago. With QPic, students can perform quantum teleportation and understand entanglement without needing to solve matrix equations. (Matt Swayne, "Picturing The Future Quantum Workforce: Visual Thinking May Help Break Quantum Education Barrier," *Quantum Insider*, April 4, 2025, https://thequantuminsider.com/2025/04/04/picturing-the-future-quantum-workforce-visual-thinking-may-help-break-quantum-education-barrier/).
204. Ibid.



India

While India has the clear advantage of a large and increasingly well-educated workforce, the brain drain in the technical sector remains a significant challenge.[205] To fix this situation, India has established processes to promote quantum education.[206] IIT Madras launched an advanced course in QC technology in 2022, focusing on quantum algorithms and programming for quantum computers. IISc Bengaluru launched its Quantum Technology Initiative (QTI) in 2020 to conduct R&D in quantum technologies and establish a framework to encourage collaboration among physicists, materials scientists, computer scientists, and engineers. Other institutions, such as IIT Jodhpur, TIFR, Mumbai, IISER Pune, Raman Research Institute, Bengaluru, and the Harish-Chandra Research Institute, Allahabad, have active research programs in QC. Multiple startups, such as Globally Xanadu, Classiq, QRDLab, and QuintessenceLabs.ai, have hosted training educational institutions to help fill the talent gap.[207] T-Hubs and top quantum computing research institutes are all engaged in this task, with varying degrees of success.[208]

In 2024, India announced its first undergraduate minor program in quantum technologies. It was launched by the All India Council for Technical Education in collaboration with the National Quantum Mission, and is likely to be open to engineering students from their third or fourth semester.[209]



Australia

Australia has one of the largest quantum workforces in the world and is home to world-leading quantum companies. The Australian government is backing this industry with a National Quantum Strategy funded with up to $1 billion from the National Reconstruction Fund.[210]

Australia has a long history of quantum research. Australian universities were at the forefront of research during the 1990s and 2000s, attracting researchers and funding from overseas and training more than 2,500 PhD students, particularly through investments in quantum-related research centers.[211] A 2016 survey of the quantum industry in Australia tallied about 5,000 PhD physicists.[212]

205. Ayush Jain, "Raining Quantum Investments, But Talent Still an Issue," *Analytics India Magazine*, May 2, 2023, https://analyticsindiamag.com/ai-insights-analysis/raining-quantum-investments-but-talent-still-an-issue/.
206. Tripathi, "Quantum Computing: Current Scenario and Future Prospects."
207. Ibid.
208. "NQM Landmark T-hubs Announced Lead India's Quantum Revolution," Department of Science & Technology of the Ministry of Science & Technology of the Republic of India, last modified October 1, 2024, https://dst.gov.in/nqm-landmark-t-hubs-announced-lead-indias-quantum-revolution; Dr Nivash Jeevanandam, "India's top quantum computing research institutes," *IndiaAI*, September 15, 2022, https://indiaai.gov.in/article/india-s-top-quantum-computing-research-institutes; Choucair, "Quantum Computing In India."
209. Sanjay Maurya, "AICTE and NQM launch India's first UG minor programme in quantum technologies," *Hindustan Times*, December 25, 2024, https://www.hindustantimes.com/india-news/aicte-and-nqm-launch-india-s-first-ug-minor-programme-in-quantum-technologies-101735129295081.html.
210. Liam Mannix, "Australia sets 'ambitious goal' to build first complete quantum computer," *The Sydney Morning Herald*, May 2, 2023, https://www.smh.com.au/national/australia-sets-ambitious-goal-to-build-first-complete-quantum-computer-20230502-p5d51r.html.
211. Nadine McGrath, "How Australia is at the forefront of multi-billion dollar quantum computing revolution," *Stockhead*, May 22, 2023, https://stockhead.com.au/tech/how-australia-is-at-the-forefront-of-multi-billion-dollar-quantum-computing-revolution/.
212. Sophia Chen, "The future is quantum: universities look to train engineers for an emerging industry," *Nature*, November 13, 2023, https://www.nature.com/articles/d41586-023-03511-7.

The country also boasts the creation of the National Centre for Quantum Computing, now known as the Centre for Quantum Communications, the world's oldest national quantum center, focusing on applications in silicon and photonics.[213] The Australian Research Council funds three quantum Centers of Excellence: Engineered Quantum Systems, Quantum Computation and Communication Technology, and Quantum Biotechnology. These institutions have produced over 2,000 papers and over 100 patents, including the world's first silicon integrated circuit and the first demonstration of quantum entanglement. Over 500 scientists work in these centers, collaborating across 13 Australian universities.[214]

Among other quantum achievements, Australia ranks sixth worldwide in the number of universities offering quantum research programs and eighth in its share of published quantum articles.[215] There is a large global diaspora of Australian-trained quantum scientists, and Australian scientists have founded some of the world's largest quantum startups, including Xanadu in Canada and PsiQuantum in the United States.

The benefits of international cooperation are multifold. Not only are overseas companies coming to Australia, but Australian researchers may also be able to access overseas funding, gain experience, and collaborate with researchers from abroad.

Australia still presents numerous attractive opportunities for its quantum researchers to choose to stay in the country. For example, Microsoft Quantum Sydney was established at the University of Sydney's $150 million Nanoscience Hub in 2017, where it focused on developing the hardware that would enable a classical computer to control a quantum computer. When Microsoft closed its Sydney quantum lab and offered inducements for the team to relocate to Seattle, the Australian team opted to end their collaboration with Microsoft and establish their own local initiative.[216]



RECOMMENDATIONS

In quantum education and training, the U.S. government can innnovate by incorporating a new hands-on approach to on-the-job quantum training into existing educational initiatives and research centers. As quantum technology becomes more accessible and more employees need to utilize it, the U.S. government can expand training beyond that solely for students currently in STEM. This additional educational activity could enable millions more U.S. workers to gain the economic benefits of the quantum revolution. The government can do so by creating pilot programs to train employees within its ranks. As the nation's largest employer, the government can leverage this position to build the quantum workforce of the future from within, and expand the training developed through this educational initiative as widely as possible across the U.S. economy.

Another important direction for expanding education in quantum could be to harness the power of the private sector. Initiatives from leading industry partners could drive industry standards and be adopted more widely with additional government resources and support. This could bring quantum education to a much wider population.

213. James Dargan, "State Of Australia Quantum Computing [2023]," *Quantum Insider*, May 29, 2024, https://thequantuminsider.com/2023/01/11/state-of-australia-quantum-computing-2022/.
214. Edmonstone, "Quantum technology: What's in it for Australia?"
215. Ibid.
216. Mark Whittaker, "It's not you, it's me: Sydney quantum lab's break up with Microsoft," *Forbes Australia*, August 7, 2024, https://www.forbes.com.au/news/innovation/its-not-you-its-me-sydney-quantum-labs-break-up-with-microsoft/.

- **Expand Quantum Training Programs**. U.S. agencies can incorporate quantum education and training initiatives into government departments to prepare personnel for the emerging technological landscape.
- **Use Private Initiatives to Expand Quantum Education**. Harnessing the power of the private sector could much more quickly expand the number of people trained in quantum applications.

SECURE

Achieving security via quantum technologies encompasses action in three different arenas that each country needs to consider:

1. **Geopolitics**: Governments can utilize this new technology to gain an advantage in economic or military competition. While competition with China dominates the headlines, there are real concerns that quantum technology could be yielded by an enemy such as an unfriendly regime in Russia, or Iran, or a nonstate actor such as a terrorist group or hackers. Getting an advantage in quantum technology represents a crucial step to protect one's country and get an advantage in geopolitical rivalries and alliances.
2. **Cybersecurity**: Geopolitical conditions have a direct impact on security, particularly cybersecurity. The computing power of this new technology in the hands of malicious actors could cripple the functioning of the government and the economy. The May 2022 White House Memorandum stressed that quantum technologies can create critical challenges in data protection: "a quantum computer of sufficient size and sophistication—also known as a cryptanalytically relevant quantum computer (CRQC)—will be capable of breaking much of the public-key cryptography used on digital systems across the U.S. and around the world. When it becomes available, a CRQC could jeopardize civilian and military communications, undermine supervisory and control systems for critical infrastructure, and defeat security protocols for most internet-based financial transactions."[217] The World Economic Forum has estimated that 20 billion devices will have to be upgraded or replaced to meet quantum security standards in the next two decades.[218]
3. **Supply chain security**: To ensure success in geopolitical competition and protection through cybersecurity, governments need to protect quantum supply chains. However, quantum supply chains are by necessity concentrated and capital-intensive, especially as they might differ widely depending on the technology used (superconducting quantum computing or trapped ion quantum computing, which use distinct raw materials and rely on different enabling technologies).[219]

These three arenas are interconnected in meaningful ways. In the following sections, each dimension will be examined separately to the extent possible, but they also influence one another and the decisions leaders make.

217. White House, "National Security Memorandum."
218. David Lague, "U.S. and China race to shield secrets from quantum computers," *Reuters*, December 14, 2023, https://www.reuters.com/investigates/special-report/us-china-tech-quantum/.
219. Superconducting quantum computers require dielectric resonators (manufactured only by Germany and Japan), Helium-3 (produced primarily in North America and Russia), and dilution refrigerators (commercially manufactured only by Finland, the Netherlands, and the United Kingdom). Trapped ion quantum computers, on the other hand, require rare-earth ionized materials, such as isotopically pure Ytterbium (produced primarily by China and within certain types of nuclear reactors), and 200mm sapphire wafers (produced only by Japan and Russia). (Manoj Harjani and Shantanu Sharma, "Will quantum supply chains fall victim to geopolitics?," *The Straits Times*, August 22, 2022, https://www.straitstimes.com/opinion/will-quantum-supply-chains-fall-victim-to-geopolitics.)

The National Quantum Initiative (Supply Chain Focus)

The National Quantum Initiative (NQI) is the United States' primary federal framework for advancing quantum computing, sensing, networking, and cryptography. Established in 2018, the initiative coordinates research, infrastructure investment, and workforce development across multiple federal agencies and national laboratories.

The latest reauthorization effort (2026) reflects a shift in federal policy from basic research toward industrialization and strategic supply chain resilience.

Congress introduced the **National Quantum Initiative Reauthorization Act in 2026**, which would extend the program through **2034** and authorize expanded federal investment in quantum research and infrastructure.

A central feature of the reauthorization effort is a growing emphasis on **quantum technology supply chains**. While early phases of the initiative focused primarily on basic research, policymakers increasingly recognize that U.S. leadership in quantum technology will depend on the **industrial ecosystem that produces the hardware, materials, and specialized components required for quantum systems**.

Quantum technologies rely on a complex supply chain that includes advanced semiconductors, photonic components, cryogenic systems, rare materials, and precision instrumentation. Many of these inputs currently depend on fragile or globally distributed production networks.

The next phase of the NQI therefore seeks to strengthen **domestic manufacturing capacity, trusted international partnerships, and secure sourcing of critical components**. By linking research investment with industrial capability, the initiative aims to ensure that the United States not only leads in quantum discovery but also in the **production and deployment of quantum technologies**.

Strategic Takeaways

1. **Quantum leadership requires supply chain leadership.** Control of the **manufacturing ecosystem—chips, photonics, cryogenic systems, and specialized materials—will determine which nations dominate the quantum economy.**
2. **U.S. policy is shifting from research to industrial capability.** The **2026 NQI reauthorization effort** reflects a transition from basic science toward **commercialization, infrastructure, and scalable production**.
3. **Quantum supply chains are now a national security issue.** Quantum technologies will shape **cybersecurity, communications, sensing, and defense systems**, making resilient domestic supply chains and trusted international partnerships essential.



United States

Geopolitics: The U.S. government has taken steps to restrict access to this sensitive technology. In September 2024, the Commerce Department announced export controls on quantum computing technologies alongside new controls for advanced semiconductors and additive manufacturing technologies.[220] The controls encompass key equipment, materials, and software utilized in quantum computers, as well as complete computers that meet or exceed specific performance specifications.[221] The interim final rule (IFR) issued by the Department's Bureau of Industry and Security, requires entities to obtain a license before exporting the specified items, with exceptions for countries that have implemented equivalent controls.[222] This position has continued in the Trump administration, especially given China's competitiveness in this sector.

Allies and partners have expressed concern that export controls may hinder collaboration, particularly as the United States becomes increasingly focused on developing and protecting sensitive technologies. The September 2024 IFR may mitigate some of these challenges, by adding license exemptions that allow exports and reexports to countries with similar export controls in place.[223]

Cybersecurity: In the May 2022 memorandum and the 2022 *Quantum Computing Cybersecurity Preparedness* Act, stated that "while the full range of applications of quantum computers is still unknown, it is nevertheless clear that America's continued technological and scientific leadership will depend, at least in part, on the nation's ability to maintain a competitive advantage in quantum computing and QIS."[224] The encryption standards can secure a wide range of electronic information. To this end, in August 2024, NIST published the first three cryptography standards designed to withstand cyberattacks from quantum computers. These encryptions have become standard across the industry, with four candidate algorithms being considered for the fourth round.[225] Along the way, NIST has published multiple white papers to help organizations prepare for the post-quantum cryptography transition. As the Biden administration ended, it set a timeline for the post-quantum transition and the full adoption of quantum-resistant protocols by 2030.[226]

Though a 2025 MITRE report concludes that quantum computers will not break high-security encryption for decades, it warns that the U.S. must act now to secure sensitive data against future quantum decryption threats. The Trump administration has continued this policy, considering quantum technology a strategic asset that can help keep the country competitive.

220. "Department of Commerce Implements Controls on Quantum Computing and Other Advanced Technologies Alongside International Partners," Bureau of Industry and Security, Press Release, September 2024, https://www.bis.gov/media/documents/quantum-press-release-final.pdf.
221. Taryn Plumb, "New quantum computing controls seek to advance efforts by the US and its allies and slow adversaries' production," *CIO*, September 6, 2024, https://www.cio.com/article/3509188/new-quantum-computing-controls-seek-to-advance-efforts-by-the-us-and-its-allies-and-slow-adversaries-production.html.
222. Clare Zhang, "US Puts Export Controls on Quantum Computers," *American Institute of Physics*, September 26, 2024, https://ww2.aip.org/fyi/us-puts-export-controls-on-quantum-computers.
223. Julia Dickson and Emily Harding, "Unleashing Quantum's Potential," *CSIS*, October 25, 2024, https://www.csis.org/analysis/unleashing-quantums-potential.
224. White House, "National Security Memorandum".
225. Spencer Feingold and Filipe Beato, "US unveils new tools to withstand encryption-breaking quantum. Here's what experts are saying," *World Economic Forum*, August 27, 2024, https://www.weforum.org/stories/2024/08/us-tools-encryption-breaking-quantum-computing-nist/; Gorgan Alagic et al., *Status Report on the Fourth Round of the NIST Post-Quantum Cryptography Standardization Process* (National Institute of Standards and Technology 2025), https://www.nist.gov/publications/status-report-fourth-round-nist-post-quantum-cryptography-standardization-process.
226. Matt Swayne, "Biden Expands Cybersecurity Mandate, Targets AI And Quantum Risks," *Quantum Insider*, January 17, 2025, https://thequantuminsider.com/2025/01/17/biden-expands-cybersecurity-mandate-targets-ai-and-quantum-risks/; National Security Agency, "Announcing the Commercial National Security Algorithm Suite 2.0," May 2025, https://media.defense.gov/2025/May/30/2003728741/-1/-1/0/CSA_CNSA_2.0_ALGORITHMS.PDF.

This is consistent with the National Quantum Strategy of 2018 adopted by the first Trump administration.

Supply chain: In preparing for the post-quantum transition, ensuring a sustainable ecosystem of developers, infrastructure providers, and enabling technologies is crucial. The Quantum Insider maps all hardware requirements that could affect the success of developing quantum technology. However, to obtain a comprehensive vendor market map of the quantum industry, one must access a database open only to paying institutional actors, not individuals.[227]

One part of the supply chain that is a definite weakness is the role played by critical minerals. Access to helium, erbium, neodymium, rubidium and strontium is crucial for key steps of the quantum industry.[228] The global critical mineral market is supplied by China, accounting for approximately 70 percent. American researchers might not source these elements directly from Chinese companies, but they use U.S. chemical companies that rely on Chinese supplies.[229] In addition to securing raw elements, the U.S. also relies on Chinese manufacturing companies for components required to build quantum devices. This happens because the American quantum industry is not yet large enough for local companies to be profitable in supplying quantum researchers and startups in this sector. This niche industry is not yet profitable for those who could source the parts needed to build the quantum devices.[230]



China

Geopolitics: The Chinese quantum ecosystem appears increasingly isolated due to the geopolitical context. While there is increasing cooperation in science and technology among Europe, North America, Australia, and Japan, cooperation with China is decreasing. The U.S. export control measures and outbound investment screening regarding quantum technologies explicitly target the Chinese industry.[231] For example, most of the Chinese entities in quantum technology (University of Science and Technology of China, QuantumCTek, Quantum Origin) and many others are on the U.S. Export Administration Regulations' Entity List.[232] Some in China see this as an impetus for more self-reliance rather than an impediment.[233] These restrictions extend to researchers. For instance, the passports of "strategic scientists" are held by their institutions and only released under strict conditions.[234]

There are even suggestions that China strategically seeks to close itself off. While the country benefits from open innovation environments abroad, it selectively engages with this innovation while protecting its quantum advances, creating an asymmetric knowledge-sharing

227. Matt Swayne, "The Quantum Supply Chain: Market Map & Key Players For 2026," *Quantum Insider*, December 18, 2025, https://thequantuminsider.com/2025/03/19/the-quantum-supply-chain-mapping-the-market-and-key-players/.
228. Prineha Narang and Joshua Levine, "The Supply Chain Chokepoints in Quantum," *War on the Rocks*, October 20, 2025, https://warontherocks.com/2025/10/the-supply-chain-chokepoints-in-quantum/.
229. Linda Nhon and Andreas Kuehn, "Navigating the Entanglements in the U.S.-China Quantum Technology Race," *Observer Research Foundation*, April 15, 2025, https://www.orfonline.org/expert-speak/navigating-the-entanglements-in-the-u-s-china-quantum-technology-race.
230. Dickson and Harding, "Unleashing Quantum's Potential."
231. Jacob Taylor, "US Treasury Restricts Investment in Chinese Quantum Industry," *American Institute of Physics*, October 30, 2024, https://ww2.aip.org/fyi/us-treasury-restricts-investment-in-chinese-quantum-industry.
232. Marc Julienne, "China's Quest for a Quantum Leap."
233. Zhang Weilan, "US blockades won't hinder China's quantum computing technology development: leading scientist," *Global Times*, July 26, 2024, https://www.globaltimes.cn/page/202407/1316805.shtml.
234. Antonia Hmaidi and Jeroen Groenewegen-Lau, *China's long view on quantum tech has the US and EU playing catch-up* (Mercator Institute for China Studies 2024), https://merics.org/en/report/chinas-long-view-quantum-tech-has-us-and-eu-playing-catch.

environment.[235] This inward-looking approach is particularly stark in quantum technology.[236] By limiting international collaboration, China risks hindering its progress in a field where global cooperation is not just beneficial but essential.

The United States has already announced plans to restrict U.S. firms from investing in Chinese companies, including those in Hong Kong and Macau, in three areas: semiconductors, quantum computing technologies, and certain AI systems.[237] For now, the U.S. retains its edge in quantum technologies, particularly in developing cutting-edge hardware. But as China's domestic supply chain matures, it could challenge American dominance. Export controls, such as those imposed by the U.S. on high-performance cooling systems, may delay but not halt this progress.[238]

Cybersecurity: In October 2024, Chinese researchers utilized a quantum computer developed by a Canadian company to break key components of advanced encryption standards, a state-of-the-art encryption system used by the military.[239] A closer examination revealed that while Chinese researchers had made incremental advances, the news reports exaggerated their actual accomplishments.[240] The Chinese research has shown significant progress in exploiting cryptographic weaknesses through specialized quantum techniques, but it has not demonstrated full-fledged universal quantum decryption.[241] These demonstrations reflect research-level exploration of cryptographic vulnerabilities under specific assumptions and do not represent general or operational quantum decryption capability.

In a similar vein to the U.S. and the NIST standards, China has also solicited proposals for post-quantum cryptography from the Institute of Commercial Cryptography Standards (ICCS), which operates under the Chinese Cryptography Standardization Technical Committee.[242] This suggest that China is pursuing a broader standard-setting and governance strategy that differs from U.S. and EU approaches.

Supply chain: Little public information exists about the Chinese supply chain. Several key hardware components, such as dilution refrigerators and high-quality lasers at relevant frequencies, are mostly or entirely manufactured by European or Japanese companies.[243] Currently, China still needs foreign equipment, such as electron-beam lithography, for its superconducting chips. Japan, which also restricts China's access to high-end chip production equipment, dominates the e-beam lithography market.[244]

235. Omaar and Makaryan, "How Innovative Is China in Quantum?"
236. While nearly half of U.S. research papers in quantum computing, communications, and sensing are coauthored with international partners, China's figures linger far behind (Parker et al., *An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology*).
237. Patrick Tucker, "New rule aims to stop US investors from funding Chinese AI, quantum research," *Defense One*, October 28, 2024, https://www.defenseone.com/technology/2024/10/white-house-targets-us-investments-chinese-ai-and-quantum-tech/400624/; Jim Pollard, "US Rules to Limit Investment in China's Chips, Quantum and AI," *Asia Financial*, October 29, 2024, https://www.asiafinancial.com/us-rules-to-limit-investment-in-chinas-chips-quantum-and-ai.
238. Matt Swayne, "State Vs. Market: The Pros And Cons Of China And U.S.'S Quantum Innovation Models," *Quantum Insider*, January 2, 2025, https://thequantuminsider.com/2025/01/02/state-vs-market-the-pros-and-cons-of-china-and-u-s-s-quantum-innovation-models/.
239. Allison, "Chinese scientists claim they broke RSA encryption with a quantum computer—but there's a catch."
240. Craig S. Smith, "Debunking Hype: China Hasn't Broken Military Encryption With Quantum," *Forbes*, October 16, 2024, https://www.forbes.com/sites/craigsmith/2024/10/16/department-of-anti-hype-no-china-hasnt-broken-military-encryption-with-quantum-computers/.
241. McCartney, "China's Quantum Computer Scientists Crack Military-Grade Encryption."
242. Matt Swayne, "China Launches Its Own Quantum-Resistant Encryption Standards, Bypassing US Efforts," *Quantum Insider*, February 18, 2025, https://thequantuminsider.com/2025/02/18/china-launches-its-own-quantum-resistant-encryption-standard-bypassing-us-efforts/.
243. Parker, *The Chinese Industrial Base and Military Deployment of Quantum Technology*.
244. Pao, "China's fastest yet quantum computer still way behind US."

The case of dilution refrigerators shows the challenge of getting these restrictions right. The British, Canadian, and American lists restrict the sale of these fridges, but since Finland has not finalized its lists, Bluefors could still export to China. In 2022, the Beijing Academy of Quantum Information Sciences purchased three Bluefors dilution refrigerators for 18 million RMB, after the UK refused to give an export license for similar equipment by Oxford Instruments.[245] To address this challenge, QuantumCTek and the Anhui Quantum Computing Engineering Research Center announced in February 2024 that they had started factory production of a Chinese-made dilution refrigerator, the EZ-Q Fridge.[246]

While it depends on some foreign technology, China is more likely to represent the source of some of the weaknesses in other countries' supply chains. For example, China has strengths in critical raw materials, especially silicon-28 and holmium copper.[247] According to the U.S. Geological Survey (USGS), China produces approximately 98 percent of the world's gallium supply and 60 percent of its germanium supply. Although the USGS said that Chinese antimony mine production has fallen significantly over the past several years, it remained the leading global antimony producer in 2023, accounting for 48 percent of global antimony production.[248]



245. Hmaidi and Groenewegen-Lau, *China's long view on quantum tech has the US and EU playing catch-up*.
246. Matt Swayne, "Reports: China Mass Producing Dilution Refrigerator Critical To Superconducting Quantum Computing," *Quantum Insider*, May 9, 2025, https://thequantuminsider.com/2024/02/28/reports-china-mass-producing-dilution-refrigerator-critical-to-superconducting-quantum-computing/.
247. Hmaidi and Groenewegen-Lau, *China's long view on quantum tech has the US and EU playing catch-up*.
248. Charlotte Trueman, "US gov't strengthens regulations prohibiting US investments in Chinese quantum and chip technologies," *Data Centre Dynamics*, October 29, 2024, https://www.datacenterdynamics.com/en/news/us-govt-strengthens-regulations-prohibiting-us-investments-in-chinese-quantum-and-chip-technologies/.

From Standardization to Migration: Operationalizing Post-Quantum Cryptography

The standardization of post-quantum cryptography (PQC) represents a critical milestone, but it marks only the beginning of what will likely be a **multi-decade transition in global cybersecurity infrastructure**. Following the publication of the first quantum-resistant cryptographic standards by the National Institute of Standards and Technology in 2024, attention is now shifting toward **implementation and large-scale migration** across government and industry systems.

Implementing PQC requires more than replacing existing encryption algorithms; it involves updating cryptographic libraries, modifying communication protocols such as TLS, upgrading hardware security modules, and ensuring interoperability across complex digital ecosystems. To manage this transition, many organizations are adopting **hybrid cryptographic approaches**, combining classical algorithms with PQC mechanisms to maintain compatibility while improving resilience against future quantum attacks.

Federal cybersecurity guidance from agencies such as the Cybersecurity and Infrastructure Security Agency and the National Security Agency emphasizes the importance of inventorying cryptographic assets, developing migration roadmaps, and designing systems with **crypto-agility** so that algorithms can be updated as standards evolve. As a result, the next phase of the PQC effort is less about algorithm discovery and more about **operationalizing quantum-resistant security across national digital infrastructure**, a transition that will require sustained coordination among government, industry, and international standards bodies.

Why PQC Migration Is Difficult

Despite the availability of new standards, migrating to post-quantum cryptography presents significant operational challenges for organizations across both government and industry. One of the most difficult issues is the **cryptographic inventory problem**—many organizations lack a comprehensive understanding of where and how cryptographic algorithms are embedded within their systems, applications, devices, and supply chains. Encryption is often deeply integrated into legacy software, network protocols, hardware devices, and embedded systems that may be difficult or costly to update.

In addition, post-quantum algorithms typically have **larger key sizes and greater computational requirements** than traditional algorithms, which can affect system performance, bandwidth usage, and hardware compatibility. Organizations must therefore evaluate impacts on infrastructure ranging from identity management systems and secure communications protocols to Internet-connected devices and long-lived industrial systems. Federal guidance from the National Institute of Standards and Technology and the Cybersecurity and Infrastructure Security Agency emphasizes the importance of building **crypto-agile architectures** that allow cryptographic components to be replaced without extensive system redesign. Because of these technical, operational, and supply-chain challenges, experts widely expect the transition to quantum-resistant cryptography to unfold gradually over the next decade or more, requiring sustained coordination among technology vendors, government agencies, and international standards bodies.



European Union

Geopolitics: While the EU promotes quantum technology and extensive international cooperation, it has also demonstrated a strong inclination towards regulation. The EU has passed several landmark pieces of legislation to tackle Big Tech and regulate rapidly developing technologies. In January 2024, the European Commission proposed new initiatives to strengthen economic security. The Commission proposed listing quantum technologies as crucial for EU security and public interests.[249] Moreover, access to the considerable EU funding will not be extended to many outside actors,[250] though some associated countries are considered.[251]

Cybersecurity: During her confirmation hearings in November 2024, Henna Virkkunen, EU Executive Vice-President for Tech Sovereignty, Security, and Democracy, outlined an ambitious vision for European leadership in quantum technologies but stressed the importance of using these technologies for EU sovereignty, competitiveness, and defense capacities by reducing dependencies, securing supply chains, and ensuring that advances in quantum and other frontier technologies remain protected.[252]

Compared to the American NIST approach, Europe has adopted the EU Cyber Resilience Act in 2024 to set cybersecurity requirements for products on the EU market, and has used the Quantum Strategy to develop new approaches to quantum security.[253] Similarly, in March 2025, the UK's National Cyber Security Centre (NCSC) published a roadmap for organizations to migrate their systems, services, and products to post-quantum cryptography by 2035.[254]

Supply chain: Member States and the European Commission have increasingly sought to shield the supply chains of sensitive quantum technologies from strategic competitors, particularly China, while also reducing dependence on non-European suppliers.[255] A major concern has been that European firms continue to supply key enabling technologies used in foreign quantum programs, including in China. Earlier export-control efforts were fragmented across national jurisdictions. For example, the Netherlands, Spain, France, the United Kingdom, and Finland introduced varying permit requirements for the export of quantum-related equipment.[256] These inconsistencies created regulatory gaps that could be exploited.[257] However, the European Union has since moved toward greater harmonization of quantum-related export controls. In September 2025, the European Commission adopted an updated EU Dual-Use Control List, which entered into force on November 15, 2025, adding EU-level controls on quantum computers, cryogenic electronic components, parametric signal amplifiers, cryogenic cooling systems, and cryogenic wafer probers.[258] While this harmonization effort reduces some of the regulatory fragmentation that previously existed among Member States, implementation and enforcement challenges remain across the European quantum supply chain.

249. Baker, "Quantum needs more investment."
250. Pieter Haeck, "Europe is ring-fencing the next critical tech: Quantum," *Politico*, February 27, 2024, https://www.politico.eu/article/how-europe-ring-fencing-quantum-computing-technology-defense/.
251. Nicholas Wallace, "Europe loosens funding rules for non-EU quantum and space researchers," *Science*, June 16, 2021, https://www.science.org/content/article/europe-loosens-funding-rules-non-eu-quantum-and-space-researchers.
252. Matt Swayne, "EU's New Technology Chief Prioritizes Quantum For Europe's Sovereignty," *Quantum Insider*, November 18, 2024, https://thequantuminsider.com/2024/11/18/eus-new-technology-chief-prioritizes-quantum-for-europes-sovereignty/.
253. Ryan Mackie, "An Overview of the EU Cyber Resiliency Act (EU CRA)," *Cloud Security Alliance*, November 18, 2025, https://cloudsecurityalliance.org/blog/2025/11/18/an-overview-of-the-eu-cyber-resiliency-act-eu-cra#; European Commission, "The EU's plan to become a global leader in quantum by 2030."
254. James Coker, "EU Launches Plan to Implement Quantum-Secure Infrastructure," *Infosecurity Magazine*, July 4, 2025, https://www.infosecurity-magazine.com/news/eu-plan-quantum-secure/.
255. European Commission, "A secure and sustainable supply of critical raw materials in support of the twin transition," Brussels, March 16, 2023, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023DC0165.
256. Hmaidi and Groenewegen-Lau, *China's long view on quantum tech has the US and EU playing catch-up*.
257. Ibid.
258. European Commission, "2025 Update of the EU Control List of Dual-Use Items," September 8, 2025, https://policy.trade.ec.europa.eu/news/2025-update-eu-control-list-dual-use-items-2025-09-08_en.



India

Geopolitics: The most significant challenge for India has been a current climate in which more countries are seeking to build their own domestic quantum ecosystems rather than share findings. The U.S. is particularly focused on timetables for export controls and security classifications for quantum devices.[259] Another difficulty is slow progress. Although the country boasts the second-highest number of open-access quantum computing users after the U.S., progress in quantum computing has been more challenging, with two landmark reports noting a lag in India's quantum development.[260]

Cybersecurity: For India, quantum technology is a national mission. To accomplish this goal, the Ministry of Science and Technology announced that a team of Indian scientists had created a user-friendly method for generating unpredictable random numbers. QNu Labs began with incubation at IIT Madras before moving to Bengaluru. It is now a partner of the Indian defense forces, deploying its Armos Quantum Key Distribution system. Moreover, QNu Labs has opened an office in the United States, underscoring its commitment to the "Made in India, Made for the World" slogan, which highlights the country's significant investments in quantum technology.[261]

Another breakthrough came from QuIC lab at the Raman Research Institute in Bengaluru after being incubated at IIT Madras. They created a quantum security platform designed to protect critical infrastructure and sensitive data. This platform delivers seamless cryptography management across various deployment environments (cloud, on-premises, and hybrid). It integrates a suite of quantum technologies developed by the startup, including its patented Quantum Key Distribution, Quantum Random Number Generator, Quantum Hardware Security Module, and NIST-compliant Post-Quantum Cryptography.[262]

Supply chain: There is limited information on how India is addressing the quantum supply chain. Considering the incipient nature of the quantum industry, it is unlikely that India has in-house abilities to cover its supply chain. Moreover, the fact that India's most advanced quantum computer is expected to come from IBM that, at this point, India is leveraging its advantages in software development and will focus on hardware as it develops this sector.

259. Stacey, "How India became the hottest date in quantum computing."
260. ANI, "India needs urgent quantum-ready cyber security as organisations continue to lag: PwC," *The Hindu Business Line*, November 18, 2025, https://www.thehindubusinessline.com/info-tech/india-needs-urgent-quantum-ready-cyber-security-as-organisations-continue-to-lag-pwc/article70293086.ece; Matt Swayne, "India Risks Falling Behind Without A Multi-Pronged Approach To Quantum Computing, Niti Aayog Repor Says," *Quantum Insider*, May 9, 2025, https://thequantuminsider.com/2025/03/06/india-risks-falling-behind-without-a-multi-pronged-approach-to-quantum-computing-niti-aayog-report-says/.
261. Vidyashree Srinivas, "What Quantum Cryptography Solutions Mean for India's Security," *Analytics India Magazine*, November 15, 2024, https://analyticsindiamag.com/ai-features/what-quantum-cryptography-solutions-mean-for-indias-security/.
262. Samaya Dharmaraj, "India: Quantum Security Platform to Safeguard Digital Infrastructure," *OpenGov Asia*, April 15, 2025, https://opengovasia.com/2025/04/15/india-quantum-security-platform-to-safeguard-digital-infrastructure/; Samaya Dharmaraj, "Quantum Breakthrough: Securing India's Cyber Future," *OpenGov Asia*, July 12, 2024, https://opengovasia.com/2024/07/12/quantum-breakthrough-securing-indias-cyber-future/.



Australia

Geopolitics: While cooperation is high on the agenda, competition with China and broader global quantum progress may affect collaboration. Quantum computers have been added to Australia's Defense and Strategic Goods List of controlled items facing export restrictions. Although the AUKUS partnership between Australia, the United States, and the UK includes arrangements for sharing quantum technologies, obstacles can arise as each country seeks to assert its sovereignty.[263]

Cybersecurity: Australia makes cybersecurity a very high priority. To spur development, the government allocated $12.08 million from the National Reconstruction Fund to QuintessenceLabs to support domestic manufacturing, international expansion, and the continued growth of the company's quantum-resilient cybersecurity technologies.[264] QuintessenceLabs produces both hardware and software for quantum-based encryption systems, including quantum random number generators (QRNGs) and secure key management tools. The company has already developed cybersecurity solutions for clients like JPMorgan Chase, Boeing, Westpac, Northrop Grumman, Raytheon, DARPA, and the U.S. Department of Homeland Security.[265] Interestingly, Vikram Sharma, CEO of Quintessence, claimed that this push for more cybersecurity services was motivated by a U.S. government directive requiring federal agencies and critical industries to become quantum-resilient by the early 2030s.[266] Moreover, Australia's chief cybersecurity agency has issued guidance on High Assurance Cryptographic Equipment (HACE), recommending that local organizations stop using the technology that underpins the internet's current cryptographic foundation by 2030, due to concerns that advances in quantum computing could render it insecure.[267]

Supply chain: In every government report on the quantum sector, supply-chain resilience is identified as a key security concern at the forefront of the agenda. Some solutions provided involve collaborating with long-term allies. The Quantum Development Group was established to secure resilient supply chains and foster global quantum collaboration based on shared values. The country also participates in the Multilateral Dialogue on Quantum, an initiative that aims to coordinate the international development of quantum technology. The Quad Investors Network Centre of Excellence in Quantum Information Sciences, involving Australia, the U.S., Japan, and India, aims to increase collaboration and market access among these nations. Furthermore, the Joint Technical Committee on Quantum Technologies has been set up to streamline technical standards and optimize expert resources globally.[268]

263. Susanne Lloyd-Jones and Kayleen Manwaring, "Quantum tech is a high-stakes gamble. Here's how Australia can find a way forward," *The Conversation*, August 25, 2024, https://theconversation.com/quantum-tech-is-a-high-stakes-gamble-heres-how-australia-can-find-a-way-forward-237361.
264. "Australian Government Leads $20M AUD ($12.08M USD) Round in QuintessenceLabs to Advance Quantum-Resilient Cybersecurity," Quantum Computing Report, April 5, 2025, https://quantumcomputingreport.com/australian-government-leads-20m-aud-round-in-quintessencelabs-to-advance-quantum-resilient-cybersecurity/.
265. Ibid.
266. Paul Smith, "Labor bets $15m on using quantum technology to fight cyberattacks," *Financial Review*, March 31, 2025, https://www.afr.com/technology/labor-bets-15m-on-using-quantum-computers-to-fight-cyberattacks-20250330-p5lnov.
267. Thomas Claburn, "Australia moves to drop some cryptography by 2030 – before quantum carves it up," *The Register*, December 17, 2024, https://www.theregister.com/2024/12/17/australia_dropping_crypto_keys/.
268. Swayne, "Australia's State Of Quantum Update."

Some collaborations have been longstanding. Q-CTRL has integrated its error suppression technology into IBM's Quantum Services, and Diraq has partnered with Perceptia Devices to create high-speed and ultra-low-power mixed-signal semiconductor designs.[269] Additionally, Quantum Graphite and its joint venture partner, Sunlands Energy, have received a significant endorsement from the federal government, which will help the two companies develop their graphite hub to support a substantial Australia–United States graphite supply chain.[270]

RECOMMENDATIONS

Security considerations are the primary catalyst for investment in quantum technology worldwide, as nations recognize its dual potential as both a transformative capability and a strategic vulnerability. Geopolitical tensions surrounding quantum progress have intensified as countries understand that quantum technologies will fundamentally reshape cybersecurity, communications, and computational capabilities. The U.S. has positioned quantum security as a national priority through initiatives like the National Quantum Initiative and strategic competition with rivals, while China's substantial state-directed investments in quantum research, the European Union's strategic autonomy initiatives in quantum technologies, and emerging quantum programs in nations like India and Australia all reflect growing recognition that quantum capabilities will influence future national security positions. Geopolitical tensions, cybersecurity concerns, and supply chain sustainability are intertwined concerns for all countries. For the purposes of this report, the U.S. has several options to achieve quantum security in a complex global environment.

- **Coordinate export controls of quantum technologies between the U.S. and its allies**. Unilateral export controls on sensitive technology might be ineffective unless coordinated with America's allies.
- **Invest in quantum-resistant encryption**. U.S. government agencies should prioritize research and development of quantum-resistant cryptographic methods to safeguard critical communications and data. Utilizing its international position, the U.S. can lead the world in the next stage of cryptographic standards development.
- **Support supply-chain resilience through domestic investment and strategic international cooperation**. Supply-chain resilience can be achieved through both domestic investment and strategic cooperation with geopolitical allies.

269. Dr Navin Chandrasekaran, *Delivering The Quantum Promise* (The Australian National Fabrication Facility 2024), https://anff.org.au/wp-content/uploads/2024/01/Delivering-the-quantum-promise.pdf.
270. Doug Bright, "Quantum SA hub to support major Australia-US graphite supply chain," *The West Australian*, March 4, 2025, https://thewest.com.au/business/bulls-n-bears/quantum-sa-hub-to-support-major-australia-us-graphite-supply-chain-c-17925826.

COOPERATE

While competition takes the headlines, cooperation becomes even more crucial in such cutting-edge technologies as quantum. While nations and organizations compete for quantum leadership, the fundamental complexity and interdisciplinary nature of quantum technologies create compelling incentives for collaboration. The quantum revolution demands capabilities that span multiple scientific disciplines, engineering specialties, and technological domains. No single institution, company, or nation possesses all the necessary expertise, resources, and infrastructure to advance quantum technologies across all relevant areas simultaneously. This reality creates natural opportunities for mutually beneficial partnerships where different actors contribute their unique strengths while sharing in the collective advancement of quantum knowledge and capabilities. Initiatives that facilitate collaboration and technology sharing can lead to exponential growth and prevent weaknesses in the supply chain from disrupting innovation.

Some strategic benefits of quantum cooperation include knowledge multiplication that occurs when collaborative efforts generate insights and innovations that exceed what participants could achieve through independent work; acceleration effects emerge when cooperation enables parallel development efforts and reduces duplication of research activities; and supply chain resilience benefits come from cooperative relationships that create alternative sources for critical materials, components, and expertise.



United States

The United States has long understood the importance of cooperation. The government has used multiple pathways toward cooperation, including multilateral and bilateral cooperation and participation in international institutions such as NATO.

In the multilateral arena, in May 2022, the United States hosted an international roundtable with the heads of quantum strategy offices from Australia, Canada, Denmark, Finland, France, Germany, Japan, the Netherlands, Sweden, Switzerland, and the United Kingdom. U.S. allies possess distinct advantages in key areas of quantum technology that the United States can leverage to gain a strategic edge.

Bilaterally, in September 2025, the U.S. signed a memorandum of understanding with the UK covering AI, civil nuclear energy, and quantum technologies. In quantum computing, the two partners plan to establish a benchmarking task force to accelerate innovation, launch a transatlantic Quantum Code Challenge to mobilize research for real-world applications, integrate AI into quantum algorithm development, and create a U.S.-UK Quantum Exchange Program.[271]

271. The White House, "Memorandum of understanding between the government of the United States of America and the Government of the United Kingdom of Great Britain and Northern Ireland regarding the technology prosperity deal," September 18, 2025, https://www.whitehouse.gov/presidential-actions/2025/09/memorandum-of-understanding-between-the-government-of-the-united-states-of-america-and-the-government-of-the-united-kingdom-of-great-britain-and-northern-ireland-regarding-the-technology-prosperity-de/.

Another bilateral initiative promoted by the government connected the firm Quantinuum with Invest Qatar, Qatar's Investment Promotion Agency, in May 2025. The collaboration is intended to support Quantinuum's expansion into the region and will enable Qatar to adopt more quantum technologies, enhance local research and development (R&D) capabilities, create high-skilled jobs, and train the next generation of the quantum workforce.[272]

Using NATO as a platform is another option. NATO has created DIANA and the NATO Innovation Fund (NIF). DIANA has a network of more than 200 accelerator programs and test centers across NATO member states, linking startups with operational end users. The NIF is the first multi-sovereign venture fund with a budget of about $1.04 billion.[273]

Collaboration is also a cause for renegotiations. Australia and the UK have eased technology transfer restrictions, with 80 percent of defense-related exports now exempt.[274] This has inspired India and Japan to propose similar policies, especially in the quantum sector.[275]



China

For years, Europe has been at the cutting-edge of cooperation with China. This has changed dramatically as the U.S. has tightened its controls, and as European partners have become more aware of the ties Chinese universities have with the defense sector in China.[276] After 2019, the tide began to turn as numerous reports revealed the deep connections between Chinese higher education institutions and the military establishment.[277] While most European countries are distancing themselves, Italy has sought renewed scientific collaboration with China.[278]

Instead, China has fostered collaborations with countries that Western powers might not seek out:

- China and Colombia signed a Memorandum of Understanding in Bogota to enhance bilateral collaboration in Artificial Intelligence (AI) and Quantum Sciences and Technologies.[279]
- China conducted a 10-day experiment with Stellenbosch University in South Africa, where a quantum key distribution link was established using the Jinan-1 satellite, generating a secure key generation rate of 1.07 million bits over 12,900 km.[280]

272. "Invest Qatar partners with Quantinuum to accelerate expansion and advance the region's quantum computing ecosystem," May 20, 2025, https://www.quantinuum.com/press-releases/invest-qatar-partners-with-quantinuum-to-accelerate-expansion-and-advance-the-regions-quantum-computing-ecosystem#.
273. Masafumi Ishii, "Prospects of NATO-IP4 Cooperation in Quantum Technology," *Cooperation between European and Indo-Pacific Powers in the US alliance system project: Policy Paper* 12 (2025): https://www.spf.org/iina/en/articles/masafumi_ishii_01.html.
274. Cierra Choucair, "India May Likely Push For Expanded Access To Quantum And Emerging Technologies In US Trade Talks," *Quantum Insider*, April 28, 2025, https://thequantuminsider.com/2025/04/28/india-may-likely-push-for-expanded-access-to-quantum-and-emerging-technologies-in-us-trade-talks/.
275. Cierra Choucair, "The State Of US Quantum In Flux As Partnerships With India And Japan Reaffirmed Amid Research Cuts And Proposed Funding," *Quantum Insider*, February 14, 2025, https://thequantuminsider.com/2025/02/14/the-state-of-us-quantum-in-flux-as-partnerships-with-india-and-japan-reaffirmed-amid-research-cuts-and-proposed-funding/.
276. Jeroen Groenewegen-Lau, "Europe must end its quantum technology research with China," *Mercator Institute for China Studies*, June 25, 2024, https://merics.org/en/comment/europe-must-end-its-quantum-technology-research-china.
277. David Matthews, "European universities under fire over work with Chinese military," *Science|Business*, June 16, 2022, https://sciencebusiness.net/news/european-universities-under-fire-over-work-chinese-military.
278. Gabriele Carrer, "Italy and China renew scientific cooperation protocol: what it entails," *Decode39*, November 29, 2023, https://decode39.com/8382/italy-china-scientific-cooperation-protocol/.
279. "Colombia and China deepen scientific cooperation in AI and quantum technologies," TV BRICS, June 20, 2025, https://tvbrics.com/en/news/colombia-and-china-deepen-scientific-cooperation-in-ai-and-quantum-technologies/.
280. Bai Ge, "World Insights: Collaboration is key to building quantum future, say South African scientists," *Xinhua*, March 22, 2025, https://english.news.cn/20250322/2e559bd542044e96ae1af60ab41efb5b/c.html.

- Before the war in Ukraine, Russia had quantum collaborations with many universities in Europe (e.g., Oxford) and the U.S. (e.g., MIT). Russia was even participating in the European Union's Quantum Flagship program.[281] After the start of the war, only the collaboration with China remains. China and Russia have tested an "unbreakable" quantum satellite communication system, connecting Zvenigorod near Moscow and Ürümqi in western China.[282]



European Union

European-level initiatives continue to engage internationally. For example, QuantERA, the EU's largest funding scheme supporting quantum science and innovation, has united over 41 research funding agencies from 31 countries, with more than 100 funded international projects involving nearly 550 research groups.[283] European countries, the U.S., Canada, Australia, and Japan are building a quantum technology alliance of democracies, notably excluding China from a key global forum on this critical area of research.[284]

But cooperation is thriving even outside traditional areas of geopolitical proximity. The European Union and Japan have formalized a new phase of collaboration with a new Letter of Intent signed by Henna Virkkunen, Executive Vice-President of the European Commission for Tech Sovereignty, Security and Democracy, and Minoru Kiuchi, Japan's Minister of State for Science and Technology Policy, as part of the broader EU–Japan Digital Partnership established in 2022.[285] A similarly high-level understanding has been organized with India in 2025.[286]



India

The push for quantum technology is particularly important as it comes on the heels of Chinese successes. However, unlike China, India has a significant advantage in forming international partnerships in this sector. While the U.S. has imposed various export controls on China, in June 2023, the U.S. and India established a joint Indo-U.S. Quantum Coordination Mechanism to facilitate collaboration among industry, academia, and government.[287] Moreover, in September 2024, then-President Biden and Indian Prime Minister Narendra Modi announced that the two countries would enhance scientific collaboration, including in space exploration, biotechnology, and quantum computing.[288] Similar collaborations have been flourishing with Japan, Finland, Spain, and Singapore.[289]

281. Quantum News, "Where is the Russian Quantum Computer?," *Quantum Zeitgeist*, September 28, 2024, https://quantumzeitgeist.com/where-is-the-russian-quantum-computer/.
282. Valentin Weber, "The New Quantum Technology Race," *Internationale Politik Quarterly*, March 22, 2024, https://ip-quarterly.com/en/new-quantum-technology-race.
283. Anna Korzekwa-Józefowicz, "On a quantum quest: Europe's journey towards technological innovation," *Science|Business*, April 15, 2024, https://sciencebusiness.net/news/quantum-quest-europes-journey-towards-technological-innovation.
284. David Matthews, "Western democracies craft alliance on quantum technology," *Science|Business*, May 12, 2022, https://sciencebusiness.net/news/quantum-computing/western-democracies-craft-alliance-quantum-technology.
285. "EU and Japan Deepen Quantum Cooperation Through Digital Partnership Council and Q-NEKO Project," Quantum Computing Report, May 14, 2025, https://quantumcomputingreport.com/eu-and-japan-deepen-quantum-cooperation-through-digital-partnership-council-and-q-neko-project/.
286. "A high-level European Union delegation, led by Ms Ekaterina Zaharieva, currently in India visit, today called on Union Minister for Science and Technology, Dr. Jitendra Singh and discussed primarily the StartUp and innovation collaborations," Ministry of Science & Technology of the Republic of India, February 27, 2025, https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=2106749.
287. Jeff Pao, "China, India race for 1,000-qubit quantum computers," *Asia Times*, September 20, 2023, https://asiatimes.com/2023/09/china-india-race-for-1000-qubit-quantum-computers/.
288. Ministry of Foreign Affairs, "Joint Fact Sheet: The United States and India Continue to Expand Comprehensive and Global Strategic Partnership," September 21, 2024, https://www.mea.gov.in/bilateral-documents.htm?dtl/38323/Joint+Fact+Sheet+The+United+States+and+India+Continue+to+Expand+Comprehensive+and+Global+Strategic+Partnership.
289. Stacey, "How India became the hottest date in quantum computing."

India and Australia have launched new quantum collaborations, such as the Australia-India Strategic Research Fund, which invites institutions in both countries to collaborate on research projects. For example, the Centre for Quantum Computing at the University of New South Wales and IISc Bengaluru are tackling the problem of noise in quantum electronic devices, which has led to the discovery of a new state of matter, the development of new techniques for producing atomic-scale germanium and silicon transistors, and the repeated production of quantum electronic devices with the lowest levels of electrical noise to date.[290]



Australia

Australia has established partnerships with some of the world's leading quantum technology hubs through the AUKUS Quantum Arrangement and the Quad. The United States has invested in Australia's quantum research for decades. The University of Sydney's quantum research receives funding from the U.S. Army, Navy, and Air Force, while the U.S. Army Research Office has invested around $24 million in the University of New South Wales's quantum research program.[291] In 2024 alone, U.S. Government research funding involving Australian research organizations totaled around $248 million.[292] Moreover, AUKUS has enabled these countries to ease export controls that the U.S. has recently imposed on high-tech goods.[293] Collaboration seeps through due to academic openness. For example, Google's Willow quantum chip was developed using an error-correction code originally developed by researchers at the University of Sydney in 2021.[294]

- Australian National University (ANU) has signed a memorandum of understanding with Japanese tech firm Fujitsu, under which Fujitsu will provide ANU researchers and academics with access to Fujitsu's quantum systems and simulators in Japan.[295]
- Zurich Instruments has also added its technology to the National Quantum Computing Testbed Facility (NQCT) project in Queensland, Australia.[296]
- In 2025, the Australia-India Strategic Research Fund (AISRF) announced a new round of collaborative research grants, totaling around $2.5 million, across six priority areas, including quantum computing and communications.[297]

290. Sameer Patil, "The great potential of India-Australia quantum collaboration," *The Strategist*, April 26, 2024, https://www.aspistrategist.org.au/the-great-potential-of-india-australia-quantum-collaboration/.
291. Edmonstone, "Quantum technology: What's in it for Australia?"
292. "Statement on US Government intervention in Australia–US research collaboration," News and events, Australian Academy of Science, March 17, 2025, https://www.science.org.au/news-and-events/news-and-media-releases/statement-on-us-government-intervention-in-australia-us-research-collaboration.
293. Matt Swayne, "Updated AUKUS Pact Eases Export Controls On Quantum Among Member Nations," *Quantum Insider*, August 20, 2024, https://thequantuminsider.com/2024/08/20/updated-aukus-pact-eases-export-controls-on-quantum-among-member-nations/.
294. Tom Williams, "The Australian innovation in Google's new quantum chip," *ACS Information Age*, March 10, 2025, https://ia.acs.org.au/article/2025/the-australian-innovation-in-google-s-new-quantum-chip.html.
295. "Fujitsu and ANU to bring world-class quantum computing to Australia," Press Releases, Fujitsu, July 4, 2024, https://www.fujitsu.com/global/about/resources/news/press-releases/2024/0704-01.html.
296. "Zurich Instruments Joins Australia's 1st Quantum Testbed Initiative in Queensland," HPCwire, May 22, 2025, https://www.hpcwire.com/off-the-wire/zurich-instruments-joins-australias-1st-quantum-testbed-initiative-in-queensland/.
297. Cierra Choucair, "Australia-India Strategic Research Fund Announces $2.5M For Research Projects In Quantum, Biotech, And Beyond," *Quantum Insider*, February 11, 2025, https://thequantuminsider.com/2025/02/11/australia-india-strategic-research-fund-announces-2-5m-for-research-projects-in-quantum-biotech-and-beyond/.

RECOMMENDATIONS

Despite its strategic benefits, quantum cooperation faces significant challenges that must be carefully managed to maintain effective collaborative relationships. Successful quantum cooperation requires clear frameworks for managing intellectual property rights and ensuring equitable distribution of benefits among participants.

National security considerations complicate international quantum cooperation, as quantum technologies have potential military and intelligence applications that affect national security interests. Balancing the benefits of international collaboration with security concerns requires sophisticated approaches to partnership structures, information-sharing protocols, and technology-transfer limitations. Collaboration can represent a breakthrough in this cutting-edge technology. Insulating too much can prevent American companies from accessing innovation elsewhere, and can cut them off from markets for their quantum products and services. However, a strategic deployment of collaboration can lead to exponential growth in this sector.

- **Strengthen Collaboration Across Countries and Sectors**. Establish partnerships with academic institutions, private companies, and international allies to advance quantum research, share best practices, develop a quantum-capable workforce, and open access to new markets.

Conclusion

The findings from this report on quantum technology can support a strategic roadmap for applying quantum advancements across government branches. By proactively addressing risks and leveraging the opportunities quantum technology offers, government agencies can strengthen their capabilities in cybersecurity, threat detection, disaster response, and infrastructure protection. Ensuring a quantum-ready workforce and fostering collaboration across countries and sectors will be essential for the effective integration of this transformative technology.

This report details how five important countries have pursued quantum technology programs. The innovation, investment, education, security, and cooperation strategies of the U.S., China, the EU, Australia, and India depict a complex picture of the evolving approach to this technology. Sometimes it takes decades for a true breakthrough or enough funding to be amassed, while at other periods, mere days pass between groundbreaking announcements. In recent years, governments have entered a period of intense activity across all three subfields of quantum technology, including recognition of recent advances in quantum research through Nobel Prizes in Physics in 2022 and 2025. This activity is reflected in the various ways countries seek to gain an advantage in this emerging technology.

This report makes several recommendations for the U.S. government to leverage its advantages and continue building on existing strengths.

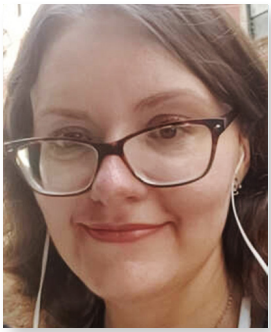
- **Continue investment in the quantum research sector.** Sustained investment will maintain U.S. competitiveness, as many other countries in this sector continue to invest significantly. The economic returns from quantum technologies promise to generate value that far exceeds research investments, while the national security implications of quantum capabilities make continued leadership imperative rather than optional.
- **Expand quantum training programs.** U.S. agencies can incorporate quantum education and training initiatives into government departments to prepare personnel for the emerging technological landscape. Expanding private educational initiatives will also strengthen the U.S. position in a highly important job market.
- **Invest in quantum-resistant encryption.** U.S. government agencies can prioritize research and development of quantum-resistant cryptographic methods to safeguard critical communications and data. Utilizing its international position, the U.S. can lead in the next stage of cryptographic standards development.
- **Support supply-chain resilience through domestic investments and strategic international cooperation.** Supply chain resilience can be achieved through both domestic investment and strategic cooperation with geopolitical allies. This will allow harnessing the power of alliances and technological complementarities among allies.
- **Coordinate export controls of quantum technologies between the U.S. and its allies.** Unilateral export controls on sensitive technology might be ineffective unless coordinated with America's allies. Leveraging coordination will enhance alliances and cooperation, leading to faster progress.
- **Strengthen collaboration across countries and sectors.** U.S. agencies can establish partnerships with academic institutions, private companies, and international allies to advance quantum research, share best practices, and develop a quantum-capable workforce.

These recommendations create a roadmap at a critical moment in the development of quantum technologies. On June 7, 2024, the United Nations proclaimed 2025 as the International Year of Quantum Science and Technology (IYQ) under UNESCO's leadership.[298] This celebration marked the 100-year anniversary of the development of quantum mechanics and spurred greater collaboration between the Global North and the Global South to ensure the development of quantum technologies worldwide.[299] Given the immense effort and support the U.S. government has invested in developing quantum technology, the recommendations in this report can help drive continued engagement in this sector and enable the government to turn these advances into tangible societal benefits.



298. "International Year of Quantum Science and Technology," UNESCO, accessed December 21, 2025, https://www.unesco.org/en/years/quantum-science-technology.
299. UN General Assembly, Resolution 78/287, International Year of Quantum Science and Technology, 2025, A/RES/78/287 (June 19, 2024), https://digitallibrary.un.org/record/4052700?v=pdf.

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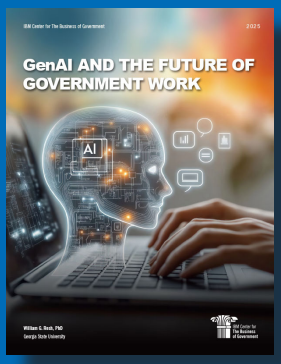
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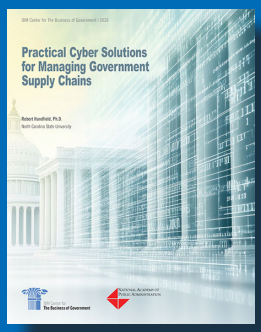
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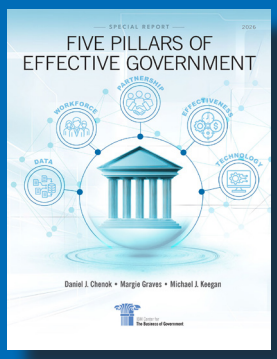
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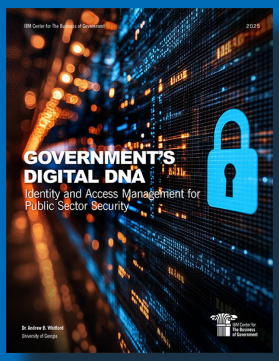
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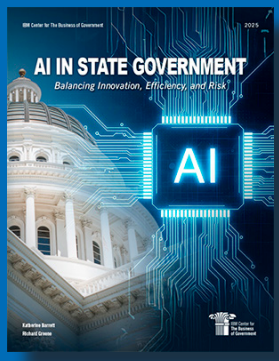
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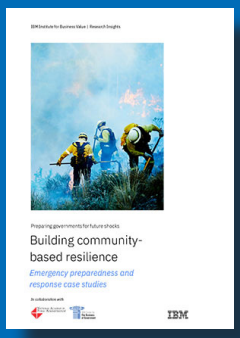
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