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Vying for Quantum Supremacy: U.S.-China Competition in Quantum Technologies

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Key Findings

- **Quantum technologies—computing, sensing, and communications—have the potential to be transformational.** Quantum technologies are advancing amid unprecedented convergence across scientific disciplines. Artificial intelligence (AI)-enabled research systems are accelerating materials discovery, drug development, and fundamental physics—fields where quantum sensing and computing will multiply capabilities. This convergence means quantum leadership is not just about a single technology domain; it is about enabling and amplifying breakthroughs across the entire innovation ecosystem. Nations that successfully integrate quantum with AI-driven research platforms will compound their advantages exponentially.
- **Quantum supremacy will be a critical national asset.** The country that achieves supremacy in quantum computing (and AI) will play an oversized role in how the digital economy is encrypted; unlock transformative advances in materials science, energy production, and medical research; and secure disproportionate and likely enduring advantages in intelligence collection and precision targeting. As the Commission’s 2025 recommendation to Congress explains, quantum is not an isolated research agenda but should be recognized as a mission-essential national asset—and the United States should mobilize resources to match that recognition.
- America still leads the world in most quantum research, but China has deployed industrial-scale funding and centralized coordination to seize dominance in quantum systems. As noted in its 2025 recommendation to Congress, the Commission assumes China is aggressively pursuing cryptographically relevant quantum computing and deliberately obscuring where its most sophisticated programs are located and how far they have progressed. In this domain, whoever gets there first could lock in irreversible strategic superiority—especially considering how exposed today’s global infrastructure remains to attacks on public key encryption systems.
- **China leads the world in quantum communications and is making rapid progress in quantum computing and sensing.** Where U.S. research and development (R&D) efforts are distributed across agencies, firms, and universities, Beijing is concentrating talent, funding, and infrastructure in a handful of promising avenues. It remains to be seen whether this centralized model or the more varied pathways pursued under the U.S. model will win the race from theory to application. The U.S. model’s distributed structure may prove advantageous in capturing convergence opportunities across quantum, AI, and other emerging technologies. China’s more centralized, state-directed approach may struggle to achieve similar cross-domain integration. In other areas of industrial policy, China has successfully used its “brute force” approach with some success.
- **China’s pursuit of quantum technologies closely aligns with national security goals.** Close integration between state research labs, defense-affiliated firms, and the People’s Liberation Army’s (PLA) acquisition system creates direct pathways for both scientific breakthroughs to inform military procurement and defense requirements to steer R&D, accelerating the militarization of China’s quantum advances.
- Central direction and a subordinate role for the commercial sector may constrain market-driven innovation in China’s quantum development. Most leading firms in China are spinoffs from state research labs, while private technology firms have shuttered their quantum labs, reportedly under government pressure to centralize control. While this likely means China’s quantum information science (QIS) efforts are less nimble than U.S. efforts, it also means the Party-state will continue to devote significant resources to QIS and over-invest in infrastructure to support its preferred approaches. If these efforts are successful, China’s quantum technologies will be well positioned to scale quickly.
- While Beijing typically makes a point of touting apparent achievements, it is highly secretive about most of its quantum research, restricting international collaboration and limiting data sharing, which make comparative assessments difficult. This approach is notably different from China’s support for open systems in AI. China’s reported quantum breakthroughs often lack independent verification, blurring the line between genuine scientific progress and political signaling. This opacity may obscure the true maturity of China’s capabilities, heightening the risk of miscalculation about both its technological readiness and its underlying intentions.

Introduction

Perhaps because they are still largely in the development phase, technologies based on QIS—the use of quantum physics to store, transmit, manipulate, or measure information—have not received the same level of public attention as AI, but the societal transformations and strategic advantages they could enable may be just as profound.¹ Advances in QIS underpin developments in quantum computing, sensing, and communication, each of which will have clear strategic implications when fully developed.² Quantum computers can perform certain types of calculations exponentially faster than today’s most advanced supercomputers and will be able to solve problems supercomputers are effectively unable to solve.³ Quantum sensing involves highly precise measurements that are not possible using current tools and could be used for a variety of purposes, from helping to detect submarines and stealth aircraft to refining the fidelity of medical imaging to revolutionizing the search for oil, minerals, and gas.⁴ Quantum communication will potentially create more secure methods of sending and receiving information and may one day enable a powerful network across quantum technologies for sensing, processing, and securing data.⁵

China and the United States each recognize the economic and security benefits to be gained by being the first country to harness these varied quantum technologies. In each country, billions of dollars are being invested to advance quantum research, albeit through different development pathways.⁶ China has instituted a focused, top-down, state-driven model to drive QIS advancement. The United States has chosen to rely primarily on its robust innovation ecosystem, which includes not only the Federal Government but also academia and the private sector. The separate actors in the U.S. system advance QIS in different but often reinforcing ways. While elements of quantum technologies are still nascent, scientists and engineers have seen rapid progress in the last decade, and many experts predict that the next several years will see critical breakthroughs in key aspects of QIS.*

Quantum Literacy: Key QIS Concepts

Quantum bit and quantum superposition: A quantum bit, or qubit, is the basic unit of information in many QIS technologies. While a classical bit has a value that is either 0 or 1, qubits can exist as a probability of being both 0 and 1 at the same time—a phenomenon known as quantum superposition—and collapse to one of the possible states upon measurement. Qubits and quantum superposition let quantum computers explore multiple possibilities in parallel, greatly speeding computing for certain problems.⁷

Quantum entanglement: Entanglement is a quantum mechanical process whereby two or more qubits become linked in such a way that the state of one qubit gives information about the other, irrespective of distance.⁸ Quantum entanglement is used in some types of computing, high-precision sensing, and secure quantum communications.⁹

Interference: Because a qubit can be in superposition of multiple states, those states can interfere with each other; however, interference can cause predictable patterns when the particle is measured. Quantum algorithms take advantage of interference—some types of interference can be used to amplify the probability of the correct solution (constructive) while other types decrease the probability (destructive)—to arrive at the correct answer faster without needing to try every option.¹⁰

Decoherence and noise: Qubits in superposition or entangled states are extremely fragile, and even a slight disturbance from the external environment can cause them to decohere and “collapse,” losing their superposition or entangled state and the related information.¹¹ The disturbances, sometimes called “noise,” that cause decoherence can take on many forms, including electromagnetic interference, thermal fluctuations, and mechanical vibrations.¹² Reducing noise and preventing unwanted decoherence are some of the biggest engineering challenges across quantum technologies.¹³

Error correction: Because qubits are so unstable, quantum computers are prone to error at a much higher rate than classical computers. To overcome decoherence, quantum scientists and engineers employ “quantum error

* This paper was informed by the Commission’s fact-finding trip to southern California to visit labs, federally funded research and development centers, and universities involved in quantum technologies. As part of that trip and separate research, the paper reflects conversations with numerous scientists, researchers, academics, company executives, government officials, and investors.

correction”—various techniques to provide more reliable computing. One notable error correction approach is a “logical qubit,” which uses quantum entanglement to encode a single state across multiple qubits.¹⁴

The Promise and Challenges of QIS

In certain areas, QIS should yield significant advantages over existing technologies, helping solve problems much faster or enabling solutions to problems that are currently unsolvable, enabling very precise sensors, and ensuring secure communications. Advances in quantum technologies require unlocking foundational science in quantum physics with applied R&D in fields ranging from chemistry and mechanical engineering to materials science.¹⁵ In fact, some capabilities that are theoretically possible in quantum physics may not be practical to design and build due to chemical, physical, or cost limitations. Even after these problems are solved, the challenge shifts to developing the hardware and specialized software so that quantum technologies can serve specific use cases at scale.¹⁶ Unlike other technologies—even many other emerging fields—quantum technologies are much more of a race to solve a set of diverse and novel problems rather than refining or iterating on existing capabilities. Because of this, the first country to successfully deploy viable quantum technologies at scale will have a durable first-mover advantage.¹⁷

Quantum Computing

Quantum computing promises to solve certain types of problems exponentially faster than classical supercomputers. In 2024, Google’s quantum computer, Willow, performed a standard benchmark computation in less than five minutes that would have taken the world’s fastest supercomputer ten septillion years to complete.¹⁸ This feat takes advantage of the efficiencies of quantum computing described above: where the computational power of a classical computer increases linearly with the addition of more bits, the computational power of a quantum computer increases exponentially with the addition of more qubits.¹⁹

Quantum computers involve many challenges, however. Because qubits are so susceptible to decoherence, scientists and engineers must find ways to reduce “noise” and develop error correction techniques.²⁰ Researchers are pursuing multiple approaches to build stable quantum computers, each of which has distinct advantages and disadvantages.²¹ The various approaches involve creating and manipulating qubits in different ways and require distinct hardware and software.²² Much of this hardware and software is still being developed and is custom made. During the Commission’s June 2025 fact-finding trip focused on the U.S. domestic quantum ecosystem, Commission Members spoke with government, private-sector, and academic scientists and researchers working on a range of quantum computing approaches. (See Appendix 2 for a chart providing an overview of the various quantum computing pathways.) There is no clear consensus on which of these approaches will lead to a viable quantum computing solution or whether multiple viable approaches will eventually coexist.²³

Applications of Quantum Computing

Quantum computers are suited for modeling and simulating the behavior of physical systems, identifying both patterns and structures in information.²⁴ Quantum computers are expected to provide breakthrough capabilities in the following areas:

- Optimization challenges in fields like supply chain logistics and finance;²⁵
- Protein folding, drug discovery, and biomaterials science;²⁶
- Simulating chemical reactions and molecular interactions, including materials science application such as battery development and superconductors;²⁷
- Modeling complex scientific simulations, including as they relate to nuclear fusion research;²⁸
- Financial modeling and risk analysis;²⁹ and
- Weather modeling and prediction.³⁰

Quantum computers may also be integrated with classical supercomputers, potentially offering processing power and speed greater than either could provide alone.³¹

From a national security perspective, quantum computers will profoundly affect communications and data security and provide significant intelligence and military advantages.

- Quantum computing could be leveraged to break pre-quantum encryption, such as Rivest-Shamir-Adleman (RSA) encryption and other public key cryptography (PKC)).*³² Especially when combined with cyber infiltration capabilities, the first country to achieve quantum advantage will be able to put at risk essentially all encrypted data—communications, financial information, health information, and sensitive government information. Adversaries, like China, are already engaged in “harvest now, decrypt later” operations—collecting encrypted data today with the intent to decrypt it once quantum computers become available.³³ Quantum computing will give the first-mover country an unparalleled advantage in intelligence. This threat extends to cryptocurrencies and blockchain-based systems, which rely on the same vulnerable encryption standards.³⁴
- Quantum computers also may be able to streamline complicated military problems related to personnel and resource allocation, logistics, and strategic planning.³⁵
- Because of their ability to handle complex probabilistic computing more efficiently than classical computers, quantum computers could consider a range of different geopolitical, social, and economic variables to predict where a conflict or flashpoint might occur.³⁶
- Quantum computers could also simulate complex battlefield environments, which could enhance wargaming and military decision-making.³⁷

Quantum Sensing

Quantum sensing uses quantum-based instruments to measure physical quantities, including time, temperature, distance, gravity, and electric and magnetic fields, with more sensitivity and precision than conventional sensors and measuring instruments—in some cases, orders of magnitude more sensitive.³⁸ Quantum sensors—which can include atom/ion-based sensors (e.g., atomic clocks, inertial sensors), photonics and light-based sensors (e.g., quantum LIDAR and radar, ghost imaging), magnetometry, and radiofrequency/microwave sensors—“promise sensitivity and precision that could revolutionize industries from healthcare to defense.”³⁹ Different types of quantum sensors may rely on distinct quantum phenomena and involve separate scientific and engineering challenges despite synergies across categories.⁴⁰

The practical use of quantum sensing, however, is not without its challenges. Some sensors are very large and have high power consumption; for more practical and widespread use, scientists and engineers will need to develop versions that are more manageable in size and require less energy.⁴¹ Additionally, quantum sensors are often expensive and highly complex, requiring quantum physicists to operate; practically speaking, this may reduce their availability and use cases.⁴² Similar to other quantum technologies, many types of quantum sensing require complex and delicate systems (e.g., involving cryogenics, vacuums, or precise lasers), meaning practical applications require overcoming “noise” from external conditions.⁴³

* The U.S. National Security Agency (NSA) has advised that post-quantum cryptography (PQC)—which relies not on quantum technology but instead quantum-resistant algorithms using existing equipment—is the best mitigation measure against the decryption that will eventually be enabled by quantum computing. The National Institute of Standards and Technology (NIST) released its first PQC standards in August 2024 and is working on additional standards. National Institute of Standards and Technology, “NIST Releases Draft Report on *Transition to Post-Quantum Cryptography Standards* for Public Comment,” November 12, 2024. <https://www.quantum.gov/nist-draft-report-on-pqc-transition/>; National Institute of Standards and Technology, “NIST Releases First 3 Finalized Post-Quantum Encryption Standards,” August 13, 2024. <https://www.nist.gov/news-events/news/2024/08/nist-releases-first-3-finalized-post-quantum-encryption-standards>; National Security Agency/Central Security Service, *Post-Quantum Cybersecurity Resources*. <https://www.nsa.gov/Cybersecurity/Post-Quantum-Cybersecurity-Resources/>.

Applications of Quantum Sensing

Some technologies in use today, such as atomic clocks and MRI machines, already employ quantum principles. Quantum innovation, however, is leading to a new generation of sensors with a range of applications.⁴⁴ Quantum sensors have applications in fields such as healthcare, energy, and disaster monitoring. In healthcare, quantum magnetometers are increasingly assisting in the study of human brain function and are being developed for magnetoencephalography (MEG) to diagnose conditions like epilepsy and for cardiac monitoring.⁴⁵ Scientists are also exploring quantum sensing to conduct imaging akin to magnetic resonance imaging (“quantum MRI”) on the structure of a molecule to aid in drug discovery.⁴⁶ In the energy sector, atom- and ion-based sensors like quantum gravimeters are able to detect underground density variations, which could assist in identifying mineral veins or oil reservoirs.⁴⁷ Quantum-enhanced atomic clocks could offer unprecedented timing precision critical for financial trading systems, telecommunications networks, and global positioning infrastructure.⁴⁸ Quantum gravimeters are also being explored for earthquake and volcanic monitoring, potentially enabling earlier detection of seismic events and improved disaster warning systems.⁴⁹

From a national security perspective, atom- and ion-based sensors such as atomic accelerometers and gyroscopes are being developed for GPS-independent navigation, which could have applications for a host of vehicles and weapons systems.⁵⁰ Quantum atomic clocks could also provide precision timing essential for secure communications; synchronized military operations; and resilient position, navigation, and timing (PNT) systems.⁵¹ Quantum sensors could dramatically improve remote sensing capabilities, for instance by allowing militaries to detect stealth aircraft, submarines, and hardened and deeply buried targets (HDBTs).⁵²

Quantum Communications

Quantum communications use the properties of quantum physics to transmit and receive information securely. One approach to secure communications using quantum technologies is through quantum key distribution (QKD).^{*} QKD allows sending and receiving parties to transmit an encrypted message via conventional technologies, pairing it with an encryption key using particles of light that take the form of qubits.⁵³ Should someone attempt to intercept the encrypted key, the qubit will collapse, losing its information and alerting both the sending and receiving parties to the interference.⁵⁴

In addition to secure information transfer, laboratories are using principles of quantum communications to explore construction of larger-scale quantum networks, which would connect geographically dispersed devices through photonic qubits.⁵⁵ Quantum networks could be used to link quantum sensors, enabling distributed quantum sensing for greater sensitivity and enhanced capabilities.⁵⁶ Quantum networking could also be used to connect distributed quantum computers, allowing for exponentially increased computing power.⁵⁷

As with other quantum technologies, quantum communications face a variety of research and engineering challenges in order to be fully useful. The basic technology for QKD exists, as discussed in the section on China’s quantum communications system; however, there are numerous practical limitations to implementation at scale, including hardware and infrastructure limitations and low error tolerance.⁵⁸ Similarly, while researchers have been able to build quantum networks, including some that use existing telecommunications infrastructure, they have been relatively limited in size and require the development and further refinement of numerous technologies.⁵⁹

Applications of Quantum Communications

Quantum communications technologies have obvious uses for any type of communications requiring high security (e.g., finance, critical infrastructure, and government and military systems), particularly given the apparent susceptibility of existing communications channels to hacking by state-supported actors.⁶⁰ Quantum networking will be useful as more quantum technologies come to fruition, potentially multiplying the utility and power of networked quantum systems.⁶¹

^{*} The NSA does not advise using QKD for national security systems, citing limitations in the technology itself and the equipment and infrastructure necessary to utilize it at scale. National Security Agency/Central Security Service, *Post-Quantum Cybersecurity Resources*. <https://www.nsa.gov/Cybersecurity/Post-Quantum-Cybersecurity-Resources/>.

U.S.-China Quantum Competition

The United States and China are pursuing leadership in quantum technologies through distinct approaches to innovation and integration of science and industry that reflect their broader political and economic models. The United States relies on a competitive and decentralized ecosystem in which federal agencies, private firms, and academic institutions advance complementary but often independent research agendas, encouraging diverse approaches and market-driven experimentation. By contrast, China’s government puts science in the service of national strategy, but its top-down approach has translated policy intent into tangible progress across quantum communications, computing, and sensing. This section describes China’s key policy objectives and research achievements in each field, then provides an overview of the U.S. ecosystem in QIS.

State Coordination Guides China to Early Quantum Breakthroughs

China is developing QIS through a state-led model that aligns scientific progress with industrial planning and strategic objectives. Guided by a hierarchy of five-year plans (FYPs) and science and technology strategies, Beijing has built an integrated ecosystem linking government ministries, the Chinese Academy of Sciences (CAS), state-owned enterprises (SOEs), and elite universities. Major projects such as the Micius quantum satellite, the Beijing–Shanghai Quantum Communication Backbone, and the Jiuzhang and Zuchongzhi quantum computers, described further below, demonstrate the state’s ability to scale research into flagship achievements. This approach has made China the global leader in quantum communications and a rising competitor in computing and sensing.⁶² Yet its heavy reliance on central direction, limited private-sector participation, and restricted data sharing obscure the maturity and sustainability of these advances, complicating assessments of the state of China’s QIS ecosystem and how effectively China can translate scientific breakthroughs into enduring technological and strategic advantage.

Incremental Policies and Mega Projects Build China’s Quantum Foundation

China’s quantum policy has evolved from exploratory research to coordinated industrial strategy, producing steady, state-driven gains across communication, computing, and sensing. Originating in the 1990s with the National High-Technology (863) and Basic Research (973) Programs, early initiatives focused on cultivating expertise and capacity in fundamental research (Table 1).⁶³ Driven by concerns over information security, China made rapid advances in quantum communications and cryptography beginning in the late 2000s. These advances provided both a successful policy template and a technical foundation for subsequent state-directed R&D in quantum computing and, later, quantum sensing.

In many cases, China’s quantum achievements have been driven forward by successful execution of “mega projects”: ambitious, state-directed efforts to attain discreet science or technological goals under the broader framework of technology development roadmaps, such as FYPs. Mega projects became a feature of China’s industrial policy in the 2006 Medium- and Long-Term Plan for Science and Technology Development.⁶⁴ While the state has relaxed its approach to industrial cultivation in more commercially mature technologies, mega projects remain a focusing mechanism for objectives closely tied to science. China’s numerous successes in civil space follow a similar blueprint.*

* For more on China’s advances in civil space, see U.S.-China Economics and Security Review Commission, “Chapter 7: The Final Frontier: China’s Ambitions to Dominate Space,” in *2025 Annual Report to Congress*, November 2025.

Table 1: Evolution of China’s Quantum Policies and Mega Projects

Policy	Key Objectives	Achievements and Related Mega Projects
863 Plan (originally 1986, updated later to include QIS) & 973 Plan (1997)	Supporting high-tech R&D; establishing quantum information as frontier science	Laid groundwork for quantum research infrastructure at the University of Science and Technology of China and CAS through QKD experiments.
11th & 12th FYPs (2006–2015)	Advancing quantum communications and building research infrastructure	Launched Hefei QKD network (2008), creating one of the world’s first metropolitan-area quantum communication networks; started construction of the Beijing–Shanghai Quantum Secure Communication Backbone (2013–2020), a 2,000-kilometer (1,250-mile) fiber-based QKD network connecting major cities; demonstrated China’s early dominance in quantum communication infrastructure.
Strategic Priority Program on Space Science (2011)	Integrating QIS into national space science goals	Launch of Micius (2016), the world’s first quantum communications satellite, enabling space-to-ground QKD and entanglement distribution.
13th FYP (2016–2020) & S&T Innovation 2030 Mega Project	Integrating communications, computing, and sensing; moving from R&D to application	Developed two quantum computers, a photonic-based system, Jiuzhang (2020), and a 62-qubit super conducting processor, Zuchongzhi (2021); integrated Micius with ground stations in Beijing, Urumqi, and Vienna, demonstrating intercontinental quantum key exchange; launched Zhaoshan Long-Baseline Atom Interferometer Gravitation Antenna (ZAIGA), an underground quantum sensing facility for testing precision measurement and gravitational detection technologies.
14th FYP (2021–2025)	“Technological self-reliance” through strengthening the role of state firms and domestic supply chains	Built Tianyan-504 quantum computer, China’s first large-scale integration of a laboratory prototype into an operational platform; expanded sensing projects.

Source: Various.⁶⁵

Security Objectives Propel China’s Early Lead in Quantum Communications

China’s earliest and most significant advances in quantum technology have occurred in quantum communications, where national security imperatives provided both motivation and focus. From the early 2000s, Chinese leaders viewed secure communications networks as essential to insulating government and military information from foreign surveillance. CAS and the University of Science and Technology of China (USTC) established an experimental QKD network in Hefei in 2008, followed by the world’s first quantum government network in Wuhu in 2009.⁶⁶ Information sovereignty concerns intensified after the 2013 unauthorized disclosures by a U.S. National Security Agency (NSA) contractor, which catalyzed new investment in QKD as state planners sought to obtain “unhackable encryption” and reduce dependence on foreign information infrastructure.⁶⁷ Between 2012 and 2013, QKD-related patent applications by Chinese firms doubled from under 20 to nearly 40 and have continued to rise rapidly.⁶⁸

The centerpiece of this effort was the Micius quantum science satellite, launched in August 2016 as part of CAS’s Strategic Priority Program on Space Science.⁶⁹ Within its first year, Chinese scientists used the satellite to set a record for satellite-to-ground quantum teleportation of entangled photons over a distance of 750 miles, far exceeding the previous record of 89 miles.⁷⁰ They also demonstrated satellite-to-ground transmission of quantum encryption keys that allowed two ground stations in China to exchange secure data at efficiencies 20 orders of magnitude greater than comparable optical fiber networks.⁷¹ In September 2017, these same systems enabled a secure 30-minute video conference between Beijing and Vienna during which scientists at CAS and the Austrian Academy of Sciences exchanged data encrypted with a quantum key.⁷²

In parallel, China pursued dedicated terrestrial quantum networks to operationalize the technology for civilian and governmental use. The Beijing–Shanghai Quantum Communication Backbone, completed in 2017, created a 2,000-kilometer (1,250-mile) fiber-optic QKD network transmitting government, financial, and other sensitive information through 32 “trusted nodes” spaced roughly every 100 kilometers (62 miles).⁷³ The system was later supplemented by a city-wide commercial network in Jinan and built out to encompass other cities.⁷⁴ By 2021, the system was serving more than 150 industrial users throughout China.⁷⁵

China’s early investments in quantum communications have now matured into an integrated system linking terrestrial fiber networks with space-based assets. In 2020, Chinese researchers connected the Micius satellite to the Beijing–Shanghai Quantum Communication Backbone, forming the world’s first integrated space–ground quantum communications network.⁷⁶ China expanded the network through the China Quantum Communication Network, which stretched over 10,000 kilometers (6,200 miles) and incorporated 145 backbone nodes, 20 metropolitan networks, and six ground stations connected to the Jinan-1 quantum microsatellite as of August 2025.⁷⁷ Together, these components form a continuously operating network that covers 17 provinces and 80 cities, positioning China far ahead of any other country in scaling quantum encryption infrastructure.⁷⁸ **Beijing is likely envisioning a constellation of quantum microsatellites coupled with this extensive fiber network to enable global, quantum-encrypted communications linking government, military, and financial users—an ambition that underscores the national security logic driving its sustained investment in quantum technologies.**⁷⁹

Given its early start and notable successes, China’s commercial quantum communications efforts are more mature than those in other quantum technologies, though its emerging ecosystem remains tied to state funding and objectives. QuantumCTek (Guodun Quantum), founded in 2009 by Pan Jianwei’s USTC research team, now provides the core hardware for China’s quantum secure communications infrastructure, while systems integrators and telecommunications companies assemble end-to-end networks using conventional optical components. Although the company has yet to post consistent profits, its 2020 listing on the Shanghai Stock Exchange and the 2024 acquisition of a 23 percent stake by China Telecom underscore state confidence in its long-term role as a national supplier.⁸⁰

While China has made notable progress in quantum communications research, its deployed systems face significant technical limitations. **The infrastructure relies on trusted relay nodes where encryption keys must be decrypted and re-encrypted at intermediate stations, creating security vulnerabilities and limiting true end-to-end quantum security and global scalability.**⁸¹ Additionally, many of China’s systems use simpler technical approaches rather than the end-to-end quantum entanglement needed for true quantum networks, raising questions about whether the infrastructure delivers the advanced capabilities that Chinese officials have publicly claimed.⁸²

State Coordination Drives Rapid but Uneven Quantum Computing Progress

After securing an early lead in quantum communications, China’s policy focus in quantum technology shifted to developing quantum computing, a more challenging but strategically significant undertaking. Spurred in part by a sense of urgency following Google’s 2019 announcement of “quantum supremacy,” U.S. sanctions and export controls on telecommunications firm Huawei and PLA-affiliated supercomputing labs around the same time deepened Beijing’s determination to find alternative technologies for advanced computing not vulnerable to such controls.⁸³ Under the 13th FYP for National Science and Technology Innovation (2016–2020), CAS launched the Science and Technology Innovation 2030 Major Project on Quantum Communication and Computers, which elevated quantum research to the level of a national mega project.⁸⁴ The plan called for developing “general-purpose quantum computing prototypes and practical quantum simulators,” signaling a

transition from foundational research to applied development.⁸⁵ The 14th FYP (2021–2025) elevated the importance of quantum technologies while simultaneously stressing the need for “technological self-reliance and self-strengthening,” emphasizing the importance of insulating China’s innovation ecosystem from foreign supply chain dependencies.⁸⁶

High-level policy commitment produced a series of research breakthroughs propelling China to near parity with the United States in developing a superconducting quantum computer and leadership in boson sampling, an approach to photonic quantum computers that works on a narrow range of algorithms.⁸⁷ At USTC, researchers unveiled the Jiuzhang photonic quantum computer in 2020, which performed a boson-sampling task in 200 seconds that would have taken a classical supercomputer an estimated half-billion years.⁸⁸ Within months, USTC debuted the Zuchongzhi superconducting quantum computer, a 62-qubit system that later expanded to 176 qubits and achieved another claimed instance of “quantum advantage.”⁸⁹

Following USTC’s breakthroughs, China’s quantum computing effort has expanded beyond university laboratories to state-guided industrial applications, reflecting a shift in policy focus from fostering individual scientific achievements to building institutional capacity and industrial ecosystems capable of scaling them.

In 2024, the Ministry of Industry and Information Technology (MIIT) and other agencies issued a directive outlining priorities for commercialization of “industries of the future,” including QIS.⁹⁰ In December that year, China Telecom Quantum Group, CAS, and QuantumCTek announced the Tianyan-504 superconducting quantum computer, a system CAS indicated would integrate into the Tianyan quantum computing network, the country’s state-run cloud platform for quantum research and development.⁹¹ In 2025, China Telecom Quantum Group and QuantumCTek followed up with Zuchongzhi-3, another superconducting quantum computer designed by USTC for commercial use, with 105 qubits.⁹² The system also became accessible to remote users via the Tianyan quantum computing network in October 2025.⁹³

Mostly recently, in late October 2025, Chinese media reported that China’s first neutral-atom quantum computer was entering commercial deployment, with a unit delivered to a subsidiary of state-owned telecommunications firm China Mobile and another on order for export to Pakistan.⁹⁴ Initially unveiled in June 2024, the 100-qubit Hanyuan-1 was built by CAS’s Innovation Academy for Precision Measurement Science and Technology in Wuhan, along with Wuhan University, Huazhong University of Science and Technology, and other local partners.⁹⁵ The rapid progression from laboratory to commercial deployment underscores China’s capacity to move scientific breakthrough quickly into application through industrial strategies like building regional clusters.⁹⁶ Local firms in Wuhan’s “Optics Valley” supplied the high-end lasers and optoelectronics used in the system—an achievement the *Hubei Daily* hailed as evidence of China’s progress in reducing dependence on foreign components.⁹⁷

State Dominance and Uneven Commercialization in China’s Quantum Industry

Despite impressive achievements by state-affiliated research institutes and universities, China’s quantum industry is nascent compared to the U.S. commercial quantum ecosystem and remains heavily shaped by government coordination and state ownership. Many of China’s prominent quantum firms, including QuantumCTek and Origin Quantum, are CAS spinoffs or have other state ties.⁹⁸ A 2022 report comparing the U.S. and Chinese industrial base in quantum technologies found that only 13 companies in China have made significant contributions to quantum technologies, including two research groups in major tech firms Alibaba and Baidu that have since closed their operations.⁹⁹

The subordinate position of the commercial sector is evident in its constrained global presence. Although over 30 Chinese companies have launched quantum computing businesses, only a handful are globally competitive.¹⁰⁰ In the 2025 list of 80 top quantum computing companies published by business intelligence provider Quantum Insider, just two were based in China: TuringQ and SpinQ.¹⁰¹ Other major companies include QuantumCTek in quantum communications and QBoson and Origin Quantum in computing.¹⁰²

Central and local government efforts to foster a more competitive commercial environment appear to be following China’s industrial policy playbook, with the state attempting to build regional hubs and launch new investment vehicles. Anhui Province’s National Lab for Quantum Information Science (NLQIS), completed in 2021, sits on the USTC campus in Hefei near a cluster of quantum startups along “Quantum Avenue,” an arrangement designed

to provide a shared talent pool and research infrastructure.¹⁰³ Similarly, Wuhan’s Optics Valley, noted above, is becoming a hub for photonic and neutral-atom quantum computers, where Hefei leads in development of superconducting systems.¹⁰⁴ Beijing also intends to replicate its massive state-led venture capital fund for semiconductor fabrication and design in other emerging technologies, announcing a one trillion renminbi (RMB) (\$138 billion) fund in March 2025.¹⁰⁵ The fund, which includes QIS, AI, hydrogen energy, and other sectors, aims to help startups and small and medium-sized enterprises achieve “original and disruptive innovations, facilitate core technological breakthroughs, and foster the development of strategic emerging and future industries.”¹⁰⁶

Despite this rapid progress, China’s quantum computing capabilities remain uneven and difficult to verify. Most reported results lack independent replication, and the systems themselves rely heavily on imported cryogenic, photonic, and control components. Unlike the United States, which advances through open scientific exchange and competition among firms such as IBM, Google, Amazon, and IonQ, China’s progress depends on sustained state subsidies. Nevertheless, its deliberate effort to align policy, funding, and industrial capacity has closed gaps in a field once dominated by Western research institutions. Going forward, China’s template of policy-guided mega projects may position China to continue achieving ambitious but clearly defined goals.

Quantum Sensing Extends China’s Vision of Dual-Use Innovation

As China established its lead in quantum communications and achieved early research milestones in quantum computing, state planners began expanding their focus toward quantum sensing and metrology. Unlike quantum computing, the physics behind quantum sensing is better understood and the technology relies on components that can be produced domestically. **Advances in remote sensing also have immediate defense applications in navigation, radar, precision strike, and submarine detection, for which small performance gains can yield outsized operational advantages.**¹⁰⁷ The 14th FYP (2021–2025) explicitly identified “breakthroughs in quantum precision measurement technology” as a strategic priority, linking them to the broader doctrine of technological self-reliance and self-strengthening.¹⁰⁸ The subsequent Metrology Development Plan (2021–2035), issued by China’s State Council, reinforced this emphasis, calling “to establish a national modern advanced measurement system with quantum metrology at its core.”¹⁰⁹

State investment in quantum sensing has expanded rapidly in recent years, building on earlier groundwork such as CAS’s Innovation Academy for Precision Measurement Science and Technology in Wuhan and the Zhaoshan Long-Baseline Atom Interferometer Gravitation Antenna (ZAIGA), begun in 2019 in Anhui Province. Linked to CAS, ZAIGA is a large underground complex of vacuum tunnels and atomic interferometers designed for precision gravitational-wave and geophysical experiments and is currently the largest operational quantum sensing facility of its kind.¹¹⁰ Since 2020, new initiatives under the National Key R&D Program and the 14th FYP for Science and Technology Innovation have widened this portfolio to include optical lattice clock programs, nitrogen-vacancy (NV)-diamond magnetometry, and other precision measurement projects.¹¹¹ Building on its strengths in computing, Anhui’s provincial economic planning agency also announced an RMB 2.2 billion (\$310 million) quantum precision measurement research facility in December 2024.¹¹² **Collectively, these initiatives underscore Beijing’s drive to transform quantum sensing from laboratory research into a platform for applied innovation and to strengthen domestic supply chains for high-precision instrumentation.** Chinese scientists now publish prolifically in optical clock and interferometry research, though most work remains at the experimental stage.

Despite this momentum, China’s quantum sensing advances remain largely in the laboratory and operationally unproven. In 2022, RAND experts assessed China was not yet a leader in any sub-fields of quantum sensing, citing Pan Jianwei’s observation that “China started late in quantum sensing, and there is a certain gap with developed countries.”¹¹³ In late 2024, researchers at the Mercator Institute for China Studies noted that China appeared closer than the United States to deploying some quantum sensing technologies, but progress varied between different types of sensors.¹¹⁴ **In contrast to China’s more concentrated efforts in quantum computing and communications, the underlying research for quantum sensors remains fragmented across several institutes.** Although a distributed research environment may foster experimentation, it also disperses oversight and funding, making it harder to move from laboratory prototypes to field-ready systems that already face steep engineering barriers. Nonetheless, the alignment of sensing with China’s broader defense modernization agenda suggests it will remain a funding and organizational priority in the coming decade.

United States: Robust Innovation Ecosystem Driving Quantum Progress

The United States leverages a robust QIS ecosystem—including various government entities, academic institutions, and the private sector—that is driving the development of quantum technologies. At the federal level, a range of departments and programs advance QIS technologies. These include the White House National Science and Technology Council (NSTC) and the Office of Science and Technology Policy (OSTP), the Department of Energy (DOE), the National Science Foundation (NSF), the National Institute for Standards and Technology (NIST), and the Department of Defense (DOD), among others.¹¹⁵ The U.S. academic community is also very active in QIS research, and numerous well-established companies and startups are investing in QIS research and commercialization.¹¹⁶ Many of these efforts involve public-private partnerships and consortia, helping ensure advancements are mutually reinforcing.¹¹⁷

U.S. Quantum Policy

In the United States, the government plays a significant role in developing and implementing policies that guide and bolster the QIS technology ecosystem. In 2016, the NSTC released *Advancing Quantum Information Science: National Challenges and Opportunities*, which outlined a national policy framework for advancing QIS.¹¹⁸ The document called for a whole-of-government approach, including programs to support QIS R&D and targeted, strategic Federal Government investments.¹¹⁹ The National Science Foundation (NSF) launched its Quantum Leap initiative in December 2017 and created its Enabling Quantum Leap: Convergent Accelerated Discovery Foundries for Quantum Materials Science, Engineering and Information (Q-AMASE-i) program in 2018.¹²⁰ That same year, DOE opened its Quantum Information Science Enabled Discovery (QuantISED) program to begin funding QIS research, including at its national laboratories.¹²¹

In 2018, U.S. QIS policy began to accelerate significantly because of two events. First, in September, the NSTC released a second report, entitled *National Strategic Overview for Quantum Information Science (Strategic Overview)*.¹²² To promote U.S. leadership in QIS, the *Strategic Overview* established various strategic “policy opportunities” and provided specific implementation guidance to government agencies.¹²³

Second, in December 2018, Congress passed the National Quantum Initiative (NQI) Act.¹²⁴ The NQI Act (NQIA) created the National Quantum Initiative—a ten-year federal program designed to essentially operationalize many of the “policy opportunities” found in the *Strategic Overview*.¹²⁵ The NQI’s stated purpose is to “ensure the continued leadership of the United States in quantum information science and its technological applications.”¹²⁶ It created different coordinating mechanisms and bodies, including the National Quantum Coordination Office (NQCO).¹²⁷ Additionally, the NQIA authorized NIST, the NSF, and DOE to “strengthen QIS Programs, Centers, and Consortia.”¹²⁸ Though the NQIA references these three institutions by name, the document effectively calls for the coordination of quantum activities across the Federal Government, industry, and academia.¹²⁹

Since 2018, the U.S. government has worked to translate this legislation into operational programs. As an example, within the Office of Science and Technology Policy, the White House officially stood up the NQCO to support the NQI and “serve as a central point of contact regarding Federal civilian quantum information science and technology activities.”¹³⁰ DOE has helped stand up five National Quantum Information Science Research Centers (NQISRCs) which bring together collaborative interdisciplinary teams and multiple institutions to create the ecosystem to facilitate advancements in QIS, with each leveraging different capabilities to focus on unique missions.¹³¹ The NSF launched the Quantum Leap Challenge Institutes (QLCIs), which are large-scale interdisciplinary research projects that focus on catalyzing QIS breakthroughs.¹³² The NIST established the Quantum Economic Development Consortium (QED-C) to foster increased collaboration between the government, research institutions, and the private sector.¹³³ The NQIA has driven a significant Federal Government investment in QIS. Since the NQIA was enacted in 2018 and through FY 2024, Federal Government expenditures for QIS were about \$5.1 billion.*¹³⁴

This policy architecture and funding achieved concrete outcomes and results. NSF programs have supported public-private efforts that have yielded important achievements in QIS, including longer superconducting qubit coherence times, making progress in one of the biggest challenges to quantum computing.¹³⁵ DOE NQISRCs have supported

* This includes about \$1 billion of enacted budget authority in FY 2024 but not another nearly \$1 billion in requested budget authority for FY 2025.

quantum test beds and national quantum foundries that provide shared infrastructure for academic, government, and commercial communities to help accelerate research and commercialization efforts across numerous quantum technologies.¹³⁶ DOE has also helped to advance commercial solutions by connecting researchers to commercial quantum computing resources.¹³⁷ The annual National Quantum Initiative Supplement to the President’s Budget includes detailed discussions of the research efforts, programs, centers, and other initiatives that have been supported by the Federal Government through the NQI.¹³⁸

In addition to the policy framework created by the NQIA, other pieces of legislation passed by Congress have driven QIS technology policy. The bipartisan CHIPS and Science Act authorized expanded federal quantum programs—enabling DOE, NIST, and the NSF to stand up or expand new R&D, standards, and commercialization efforts for quantum technologies; making investments in the quantum workforce; and investing in quantum networking infrastructure.¹³⁹ Congress has also used recent National Defense Authorization Acts (NDAA) to enact DOD-focused QIS provisions. For example, the FY 2024 NDAA (P.L. 118-31) contains multiple provisions related to applications across defense missions, including in quantum networking and quantum computing.¹⁴⁰

U.S. Academic and Private-Sector Overview

Unlike China’s government-led and -dominated model, non-government academia and the private sector are vital to America’s quantum ecosystem. Academic institutions play an important role in the U.S. QIS ecosystem, with many universities conducting basic research into quantum physics and core theoretical challenges of QIS. In addition, academic institutions have been central to Federal Government NQI programs—as direct funding recipients, working closely with the national labs to host various government-supported quantum research centers and often connecting such efforts with local startups and national businesses working to commercialize various quantum technologies.¹⁴¹ U.S. academic institutions also play an important role in working with international partners on QIS. For instance, the NSF-funded Global Quantum Leap program is an international “network of networks” involving several U.S. universities and institutions from Europe and Japan focused on linking nanofabrication technologies with QIS that supports international quantum research collaboration and workforce initiatives.¹⁴²

The U.S. business community is also critical to QIS progress and investment. According to publicly available information, there are over 150 companies in the United States that are focused on quantum technologies, from large companies to startups.¹⁴³ More than one-third of these are focused on quantum computing; a third on the algorithms and software needed for quantum applications; and the remainder on quantum communications, sensing, or other specialized areas focused on quantum technology.¹⁴⁴ From 2012 to 2024, U.S. private-sector firms led the world, securing a total of about \$4.945 billion in venture capital funding.*¹⁴⁵ As the Center for Strategic and International Studies’ Commission on U.S. Quantum Leadership observed, however, “Unlike other emerging technologies, many quantum technologies are too new and too experimental to solely rely on private investment. . . . Market forces alone may not ensure U.S. quantum leadership. This will change as quantum technologies mature, but for now federal spending on quantum technology represents an essential investment.”¹⁴⁶

United States Lags Behind China on Quantum Communications

The United States has steadily been advancing its quantum communications efforts, though currently experts assess that it lags behind China.¹⁴⁷ U.S. government efforts in this field have primarily focused on post-quantum cryptography and quantum networking.¹⁴⁸ Because quantum computers will break current methods of encryption, but because the NSA has taken the position that technical and hardware limitations reduce the actual security of QKD systems, the U.S. government has focused on post-quantum cryptography (PQC) algorithms for protection of communications and data rather than QKD.[†]¹⁴⁹ The NIST is spearheading this effort and has so far generated PQC “standards” and is encouraging administrators to transition to those standards.¹⁵⁰ PQC is relevant today, even though

* This figure covers venture funding, not the entirety of U.S. private sector investment in quantum; it does not include investments made within some of the largest U.S. companies working on quantum—e.g., within IBM, Google, Microsoft or Amazon. “The Quantum Index Report 2025,” *MIT Initiative on the Digital Economy*, May 2025. <https://qir.mit.edu/funding/>.

† PQC is not a quantum technology; however, it depends on classical computing and quantum-resistant algorithms. “What Is Post-Quantum Cryptography (PQC)? A Complete Guide,” *Palo Alto Networks*, accessed November 14, 2025. <https://www.paloaltonetworks.com/cyberpedia/what-is-post-quantum-cryptography-pqc>.

quantum computing has not yet developed the ability to crack pre-quantum cryptography at scale—it prevents adversaries from stealing encrypted government communications now and then using quantum computers to decipher them in the future.¹⁵¹ As quantum computing advances, the demand for new forms of secure communications—and therefore secure and scalable quantum communication technologies—is likely to grow.

U.S. government efforts have also focused on quantum networking. DOE—guided by its Quantum Internet Blueprint—is building quantum communications testbeds where researchers and companies can test capabilities in secure communications, precision timing, creating networks of quantum sensors, and, in the longer term, interconnect quantum processors.¹⁵² In Illinois, DOE labs and the University of Chicago stood up the 52-mile Argonne Quantum Loop and then extended it to a 124-mile network testbed.¹⁵³ Similar testbed networks linking universities, U.S. government labs, and other entities are being developed in Boston and Washington, DC.¹⁵⁴ U.S. companies are also working on quantum networks: Amazon Web Services (AWS) partnered with Harvard to operate a field-deployed, multi-node quantum network under Boston; Qunnect built its GothamQ quantum network in New York that currently connects government, national laboratories, university and industry users; and EPB Quantum and Qubitekk operate a commercial quantum network in Chattanooga.¹⁵⁵

Progress on Diverse Quantum Computing Pathways

Consistent with a more varied QIS ecosystem and a less top-down policy approach, the United States is leveraging its innovation ecosystem to pursue a range of approaches to quantum computing, namely superconducting, neutral-atom, trapped-ion, photonic, and topological. To date, these different approaches have yielded a range of promising results, including the following notable examples:

- IBM (superconducting) released a 1,121-qubit chip and the Quantum Nighthawk processor with 120 linked qubits that will enable computing that requires up to 5,000 two qubit-gates (expected to rise to 15,000 by 2028);¹⁵⁶
- Amazon (superconducting) is developing its own superconducting quantum processors and provides access to multiple quantum computing platforms through Amazon Web Services (AWS) Braket, including systems from IonQ, Rigetti, and Oxford Quantum Circuits;¹⁵⁷
- Google (superconducting) used its Willow processor with 105 error-correcting qubits to make a breakthrough in error correction and demonstrated a new Quantum Echoes algorithm on Willow, marking the first time a quantum computer has successfully run a verifiable algorithm that surpasses supercomputers (13,000 times faster in this case);¹⁵⁸
- Atom Computing (neutral-atom) has produced a 1,180-qubit quantum computer;¹⁵⁹
- QuEra Computing launched Aquila (neutral-atom), a special-purpose quantum computer with up to 256 qubits;¹⁶⁰
- Quantinuum and Microsoft (trapped-ion) created 12 logical qubits;¹⁶¹
- PsiQuantum (photonic) is working on fault-tolerant photonic quantum computers;¹⁶² and
- Microsoft is pursuing a topological quantum computer.¹⁶³

The more varied U.S. approach means the United States potentially has more pathways to make breakthroughs in quantum computing. On the other hand, each of these approaches currently uses largely independent hardware, processors, and software and relies on specialized knowledge not necessarily transferable across quantum computing approaches.¹⁶⁴ These challenges may make it difficult for even promising quantum computing technologies to scale or benefit from diffusion.

To some extent, the U.S. quantum technology ecosystem seeks to address these challenges through the creation of “testbeds,” shared foundries, and government-sponsored research collaborations. For example, DOE supports testbeds at Sandia (trapped-ion computing), Berkley (superconducting), and Oak Ridge National Labs (quantum networking); Q-NEXT provides quantum foundries at Argonne National Lab (semiconductor quantum systems and growing qubits) and SLAC National Accelerator Lab (superconducting); the NSF is supporting the construction of

the National Quantum Nanofab to provide an open access fab (atomic-photon quantum devices); and DOE's Co-Design Center for Quantum Advantage provides a center for co-designing materials, devices, and software and algorithms for quantum computing.¹⁶⁵ This is an area where continuing investment and additional policy innovation could be useful in helping reduce the costs to experiment with different quantum technologies, expand the quantum workforce, simplify complex supply chains, and eventually speed commercialization of whichever quantum computing technology seems most promising.

Range of Advanced Quantum Sensing Efforts

It is challenging to generalize across quantum sensing—more so than quantum computing—because of the diverse range of applications, discrete technologies, and typically smaller, niche market size across use cases.¹⁶⁶ Nevertheless, the United States is viewed by experts as the current frontrunner in quantum sensing technologies, particularly those identified as high priority by DOD.¹⁶⁷ U.S. quantum sensing efforts reflect the diverse U.S. model for QIS more broadly, with support from government agencies like the NIST and DOD, ongoing efforts at federally funded research labs such as National Aeronautics and Space Administration's Jet Propulsion Laboratory, and innovation and investment led by private-sector companies ranging from well-established enterprises to startups.¹⁶⁸

Considerations for Congress

The Commission undertook extensive fact-finding and expert consultations on quantum technologies and their importance to U.S. economic and national security throughout its 2025 annual report cycle. Within the 2025 Annual Report, the Commission included as one of its top ten recommendations to Congress a recommendation focused on ensuring the United States achieves quantum leadership before China can leverage these capabilities against U.S. interests (see Appendix 1).

Appendix 1: 2025 Annual Report “Quantum First” Recommendation

Congress establish a “Quantum First” by 2030 national goal with a focus on quantum computational advantage in three mission-critical domains—cryptography, drug discovery, and materials science. To achieve this ambitious national goal, the Commission recommends Congress should take the following actions:

- Provide significant funding for U.S. quantum development, focused on scalable quantum computing modalities, secure communications, and post-quantum cryptography. To secure U.S. leadership, Congress should pair this funding with quantum workforce development initiatives, including expanded fellowships, talent exchange programs with allies, and dedicated curricula aligned with mission needs.
- Prioritize modernization of enabling infrastructure, including cryogenic laboratories, quantum engineering centers, and next-generation fabrication and metrology facilities. These assets are essential to converting scientific discovery into deployable systems, and many current research environments remain under-resourced or technologically outdated.
- Establish a Quantum Software Engineering Institute (QSEI) focused on developing the software foundations for scalable, secure, and interoperable quantum computing. The QSEI should also coordinate an open-source ecosystem to accelerate application development and build a trusted quantum software supply chain. Modeled on the National Artificial Intelligence Research Institutes and National Manufacturing Institutes, QSEI would ensure that U.S. quantum hardware is matched by world-class software capabilities, enabling early operational advantage across science, industry, and defense.

Whoever leads in quantum (and AI) will control the encryption of the digital economy, enable breakthroughs in materials, energy, and medicine, and gain asymmetric and likely persistent advantage in intelligence and targeting. It is imperative that America treat quantum not as a research silo but as a mission-critical national capability—and act accordingly.

While the United States retains world-leading research capabilities, China has mobilized state-scale investment and industrial coordination to dominate quantum systems and standards. For the purposes of this recommendation, the Commission presumes that China is actively racing to develop cryptographically relevant quantum computing capabilities and is likely concealing the location and status of its most advanced efforts. This is a domain where first-mover advantage could yield irreversible strategic consequences, particularly given the vulnerability of current global systems that rely on public key cryptography.

The Quantum First 2030 timeline is essential to ensure the United States achieves quantum leadership before any adversary can leverage these capabilities against American interests. Quantum technologies—spanning computing, sensing, and communication—will shape the future of strategic advantage.

Appendix 2: Top Approaches to Quantum Computing

Quantum Computing Approach and Brief Description	Pros and Cons of Approach	Examples of Entities Working on the Approach
<p>Superconducting quantum computers build qubits by cooling, to near absolute zero, superconducting electric circuits. When brought to temperatures that low, these circuits become solid-state qubits and can then be manipulated.</p>	<p><i>Pro:</i> Building the superconducting electric circuits relies on fabrication techniques that have largely already been mastered. This potentially makes scaling the qubits needed for a superconducting quantum computer easier to achieve. These types of quantum computers are also able to perform operations in nanoseconds and are believed to be among the fastest type of quantum computer.</p> <p><i>Con:</i> The qubits in superconducting quantum computers decohere quickly, the refrigeration needed is burdensome, and the wiring that these computers need is very complex.</p>	<p><i>United States</i></p> <ul style="list-style-type: none"> • Amazon Web Services • Google Quantum AI • IBM Quantum • Rigetti Computing <p><i>China</i></p> <ul style="list-style-type: none"> • Origin Quantum • QuantumCTek • Tencent Quantum Lab • University of Science and Technology of China (USTC) • Tsinghua University • Zhejiang University
<p>Photonic quantum computers use photons, individual particles of light, as qubits.</p>	<p><i>Pro:</i> Perhaps the greatest advantage to a photonic quantum computer is that it can operate at or near room temperature.</p> <p><i>Con:</i> These computers are very large and every time a new calculation is performed, it requires arranging and rearranging different beam splitters and mirrors.</p>	<p>United States</p> <ul style="list-style-type: none"> • PsiQuantum <p>China</p> <ul style="list-style-type: none"> • Turing Quantum • USTC
<p>Trapped-ion quantum computers use a series of magnetic and electric fields to suspend or “trap” an ion. Once the ion is trapped, it can be further manipulated to achieve different quantum states and perform calculations.</p>	<p><i>Pro:</i> The qubits generated by a trapped-ion computer maintain their coherence for long periods of time. The approach also allows for the ability to more easily address individual qubits.</p> <p><i>Con:</i> Trapped-ion quantum computers perform calculations relatively slower than other types of quantum computers, and scaling up qubits is difficult.</p>	<p><i>United States</i></p> <ul style="list-style-type: none"> • IonQ • Quantinuum <p><i>China</i></p> <ul style="list-style-type: none"> • USTC • Tsinghua University
<p>Neutral-atom quantum computers are built by cooling atoms to near absolute zero temperatures and then moving them to a vacuum cell. Once there, they are specifically positioned and ultimately transformed into qubits by using laser pulses to adjust their spin.</p>	<p><i>Pro:</i> Compared to other quantum computers, neutral-atom quantum computers retain information longer, operate at room temperature (after the atoms have been cooled), and do not require complex wiring.</p> <p><i>Con:</i> It takes considerable time to measure, move, and replenish the atoms used in a neutral-atom quantum computer.</p>	<p><i>United States</i></p> <ul style="list-style-type: none"> • Atom Computing • Infleqtion • QuEra <p><i>China</i></p> <ul style="list-style-type: none"> • CAS Innovation Academy for Precision Measurement Science & Technology

<p>Topological quantum computers use quasiparticles called anyons as qubits. Quantum information is encoded in these anyons, which are then arranged or “braided” in different patterns. The braiding of the anyons in specific patterns allows for different calculations to be carried out.</p>	<p><i>Pro:</i> Because the quantum information is distributed across a physical system (i.e., the pattern) and not in individual qubits, topological qubits are less likely to lose coherence, reducing errors.</p> <p><i>Con:</i> Aspects of technology unproven; science behind creating and controlling anionic modes still developing.</p>	<p><i>United States</i></p> <ul style="list-style-type: none"> • Microsoft <p><i>China</i></p> <ul style="list-style-type: none"> • China Institute of Physics, CAS • Tsinghua University
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Source: Various.¹⁶⁹

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