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Highlights of GAO-22-104422, a report to congressional addressees

October 2021

TECHNOLOGY ASSESSMENT

Quantum Computing and Communications

Status and Prospects

Why GAO did this study

Quantum information technologies could dramatically increase capabilities beyond what is possible with classical technologies. Future quantum computers could have high-value applications in security, cryptography, drug development, and energy. Future quantum communications could allow for secure communications by making information challenging to intercept without the eavesdropper being detected.

GAO conducted a technology assessment on (1) the availability of quantum computing and communications technologies and how they work, (2) potential future applications of such technologies and benefits and drawbacks from their development and use, and (3) factors that could affect technology development and policy options available to help address those factors, enhance benefits, or mitigate drawbacks.

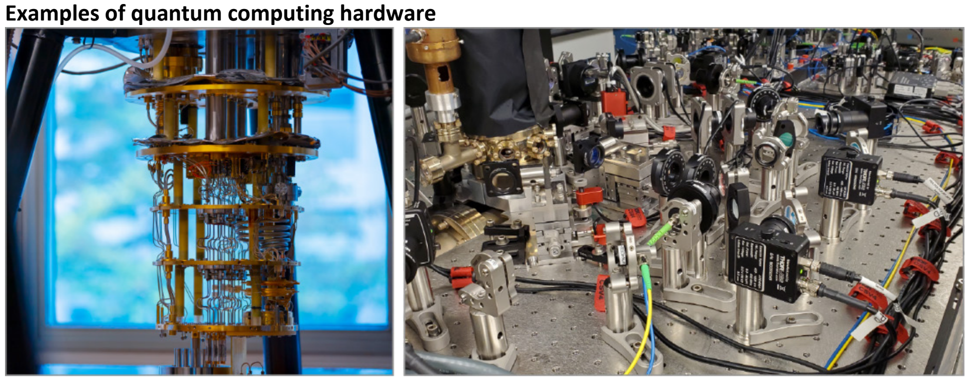
To address these objectives, GAO reviewed key reports and scientific literature; interviewed government, industry, academic representatives, and potential end users; and convened a meeting of experts in collaboration with the National Academies of Sciences, Engineering, and Medicine. GAO is identifying policy options in this report.

View GAO-22-104422. For more information, contact Karen L. Howard at (202) 512-6888 or howardk@gao.gov.

What GAO found

Quantum information technologies aim to use the properties of nature at atomic scales to accomplish tasks that are not achievable with existing technologies. These technologies rely on *qubits*, the quantum equivalent of classical computer bits. Scientists are creating qubits from particles, such as atoms or particles of light, or objects that mimic them, such as superconducting circuits. Unlike classical bits, qubits can be intrinsically linked to each other and can be any combination of 0 and 1 simultaneously. These capabilities enable two potentially transformational applications—quantum computing and communications. However, quantum information cannot be copied, is fragile, and can be irreversibly lost, resulting in errors that are challenging to correct.

Examples of quantum computing hardware



Many different types of quantum computers are being developed. The left image shows superconducting quantum computer hardware. The right image shows trapped ion quantum computer hardware.

Source: ©Intel Corporation (left photo); Chris Seck, Oak Ridge National Laboratory (right photo). | GAO-22-104422

Some quantum computing and communications technologies are available for limited uses, but will likely require extensive development before providing significant commercial value. For example, some small error-prone quantum computers are available for limited applications, and a quantum communications technology known as quantum key distribution can be purchased. According to agency officials and stakeholders, additional quantum technology development may take at least a decade and cost billions, but such estimates are highly uncertain. Quantum computing and communications technologies will likely develop together because of some shared physics principles, laboratory techniques, and common hardware.

Quantum computers may have applications in many sectors, but it is not clear where they will have the greatest impact. Quantum communications technologies may have uses for secure communications, quantum networking, and a future quantum internet. Some applications—such as distributed quantum computing, which connects multiple quantum computers together to solve a problem—require both quantum computing and communications technologies. Potential drawbacks of quantum technology include cost, complexity, energy consumption, and the possibility of malicious use.

GAO identified four factors that affect quantum technology development and use: (1) collaboration, (2) workforce size and skill, (3) investment, and (4) the supply chain. The table below describes options that policymakers—legislative bodies, government agencies, standards-setting organizations, industry, and other groups—could consider to help address these factors, enhance benefits, or mitigate drawbacks of quantum technology development and use.

Policy Options to Help Address Factors that Affect Quantum Technology Development and Use, or to Enhance Benefits or Mitigate Drawbacks

Policy options and potential implementation approaches	Opportunities	Considerations
Collaboration (report p. 37) Policymakers could encourage further collaboration in developing quantum technologies, such as collaboration among: • Scientific disciplines • Sectors • Countries	• Collaboration among disciplines could enable technology breakthroughs. • Collaboration could help accelerate research and development, as well as facilitate technology transfer from laboratories to the private sector, federal agencies, and others. • International collaboration could bring mutual benefits to the U.S. and other countries by accelerating scientific discovery and promoting economic growth.	• Intellectual property concerns could make quantum technology leaders reluctant to collaborate. • Institutional differences could make collaboration difficult. • Export controls may complicate international collaboration, but are also needed to manage national security risks.
Workforce (report p. 39) Policymakers could consider ways to expand the quantum technology workforce by, for example: • Leveraging existing programs and creating new ones • Promoting job training • Facilitating appropriate hiring of an international workforce who are deemed not to pose a national security risk	• Educational programs could provide students and personnel with the qualifications and skills needed to work in quantum technologies across the private sector, public sector, and academia. • Training personnel from different disciplines in quantum technologies could enhance the supply of quantum talent. • International hiring could allow U.S. quantum employers to attract and retain top talent from other countries.	• Efforts to increase the quantum technology labor force may affect the supply of expertise in other technology fields with high demand. • It may be difficult to adequately develop workforce plans to accommodate quantum technology needs. • International hiring could be challenging because of visa requirements and export controls, both in place for national security reasons.
Investment (report p. 41) Policymakers could consider ways to incentivize or support investment in quantum technology development, such as: • Investments targeted toward specific results • Continued investment in quantum technology research centers • Grand challenges to spur solutions from the public	• More targeted investments could help advance quantum technologies. These may include investments in improving access to quantum computers and focusing on real-world applications. • Quantum technologies testbed facility investments could support technology adoption, since testbeds allow researchers to explore new technologies and test the functionality of devices. • Grand challenges have shown success in providing new capabilities and could be leveraged for quantum technologies.	• It may be difficult to fund projects with longer-term project timeframes. • A lack of standards or, conversely, developing standards too early, could affect quantum technology investments. Without standards, businesses and consumers may not be confident that products will work as expected. • Developing standards too early may deter the growth of alternative technology pathways.
Supply Chain (report p. 43) Policymakers could encourage the development of a robust, secure supply chain for quantum technologies by, for example: • Enhancing efforts to identify gaps in the global supply chain • Expanding fabrication capabilities for items with an at-risk supply chain	• A robust supply chain could help accelerate progress and mitigate quantum technology development risks by expanding access to necessary components and materials or providing improved economies of scale. • Quantum material fabrication capabilities improvements could ensure a reliable supply of materials to support quantum technology development. • Facilities dedicated to producing quantum materials could help support scalable manufacturing of component parts needed for quantum technology development.	• The current quantum supply chain is global, which poses risks. For example, it is difficult to obtain a complete understanding of a component's potential vulnerabilities. • Some critical components, such as rare earths, are mined primarily outside of the U.S., which may pose risks to the supply chain that are difficult to mitigate. • Quantum manufacturing facilities take a long time to develop and can be costly.

Source: GAO. | GAO-22-104422