FULL COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HEARING CHARTER

"Advancing American Leadership in Quantum Technology"

Wednesday, June 7, 2023
10:00 a.m.
2318 Rayburn House Office Building

Purpose: On June 7, 2023, the Committee on Science, Space, and Technology will hold a full committee hearing titled "Advancing American Leadership in Quantum Technology." The purpose of this hearing is to evaluate the state of quantum research, development, and technology (RD&T) in the United States. The hearing will serve as an opportunity to review and discuss the first five years of the National Quantum Initiative Act (NQIA), the economic value of quantum science and its applications, the national security importance of developing quantum capabilities, and what policies should be considered in the next five years. The hearing will help inform legislation to reauthorize NQIA programs that expire on September 30, 2023.

Witnesses

- **Dr. Charles Tahan,** Director, National Quantum Coordination Office, OSTP
- **The Honorable Paul Dabbar,** Former Under Secretary for Science, U.S. Department of Energy
- **Dr. Eleanor G. Rieffel,** Senior Researcher for Advanced Computing and Data Analytics, NASA/Ames Research Center
- **Dr. Celia Merzbacher,** Executive Director, Quantum Economic Development Consortium
- **Dr. Emily Edwards,** Executive Director, IQUIST, University of Illinois

Overarching Questions

- How has the state of quantum science advanced during the first five years of the National Quantum Initiative Act?
- What programs and activities authorized under the National Quantum Initiative Act have been the most successful in advancing the state of quantum science?
- What challenges has the government, industry, and academia faced in implementing the National Quantum Initiative Act?
- What areas or policies should Congress focus on during the next five years of the quantum initiative?
- What can Congress do to meet workforce and educational needs of the quantum industry?

- Is the United States keeping pace with China in developing quantum capabilities?

Background

Basics of Quantum Physics and Mechanics: Quantum theory is the theoretical basis of modern physics that explains the nature and behavior of matter and energy on the atomic and subatomic level. The nature and behavior of matter and energy at that level is sometimes referred to as quantum physics and quantum mechanics.

Quantum physics explains the workings of atomic and subatomic particles and the tiniest packets of energy, such as photons. Quantum mechanics helps provide explanations for what happens at atomic scales. A few key properties of quantum mechanics have enabled technological breakthroughs. 1) Superposition – the ability for subatomic particles to exist in one of two states, or both states simultaneously. 2) Entanglement – the ability for subatomic particles that have been separated to instantaneously respond to each other. 3) Uncertainty – the fact that we cannot know both the precise location and state of a quantum particle at any point in time.

Quantum technology research has guided the development of technologies like lasers, magnetic resonating imaging (MRI), superconducting magnets, light emitting diodes, transistors and semiconductors/microprocessors, and electron microscopy. Quantum mechanics also creates the potential for enormous leaps in crucial areas like computing, precise measurement, cryptography, and impenetrable communications.

Quantum Information Science (QIS): Quantum information science is the marriage of information theory and quantum physics to develop new and powerful ways of processing information.

Quantum information science has many possible applications, some of which are already in use or early/mid testing phases – such as satellite communications and highly sensitive sensors. Others have the potential to mature in the next 5-10 years. Some potential applications include quantum sensors that can discover new underground oil and mineral deposits or detect seismic signals from nuclear explosions that traditional devices are not sensitive enough to discern. New portable, quantum navigation devices that are already undergoing rigorous testing would enable soldiers and weapons platforms to find their way even when GPS networks are jammed or knocked out. QIS can also help develop communications systems that would be impenetrable to both quantum and traditional cryptographic methods. China is already operating a secure quantum communications network between two of its cities and has demonstrated its operations.[1]

Quantum Computing: The basic architecture of the computer has remained essentially the same for more than 75 years. Research in advanced materials and computer science continues to push the envelope of classical computing speed and power. Nevertheless, it has been apparent for some time that the physical limits of classic computing are within view.

Quantum computing today is in its pre-market stage, but its maturation promises extraordinary improvements in computing speeds and performance over conventional computing for certain very

[1] Andrew Jones, China is developing a quantum communications satellite network, spacenews.com, 10 March 2023, available at https://spacenews.com/china-is-developing-a-quantum-communications-satellite-network/

important classes of problems.

For example, three important areas of science and technology could certainly be affected:

- Cryptography – Current encryption of electronic information is based on mathematical complexities that overwhelm the capabilities of the most powerful supercomputers. With a quantum computer, however, it is believed that every bit of electronic information, from credit card transactions to national security secrets, could be decrypted instantly.[2] Conversely, quantum-encrypted communications could be 100 percent secure for the foreseeable future.

- Chemistry and physics research – By modeling the electronic structure of large molecules, quantum computers could eliminate time-consuming and expensive trial-and error methods for developing of new advanced materials for aeronautics, pharmaceuticals, and much more.[3] Hypothesizing and verifying the performance characteristics of new materials using quantum computing capabilities could be much faster and cheaper.

- Complex data analytics – In every area of data analytics a quantum computer would possess a significant (orders of magnitude) speed advantage. Analyzing and managing trillions of bits of information moment-by-moment could be feasible.[4]

Quantum computers are not expected to replace classical computers, but their radically different way of operating enables them to perform calculations that are impossible on classical computers.[5] Classical computers encode information in bits. Each bit can represent a zero or a one. These zeroes and ones act as on/off switches that ultimately translate into computing functions.

Instead of bits, quantum computers use "qubits" which can represent a zero, one, or both at the same time. This is what enables a quantum computer to solve certain problems more quickly and efficiently.

The United States remains the front runner in quantum computing, mostly thanks to a robust private sector research and development community that includes the likes of Google, Microsoft, IBM, Amazon, and others.[6] The U.S. also has the most active quantum startup community, with dozens of innovators pushing the bounds of quantum applications across a range of use cases.[7] This ecosystem is why the United States holds a significant lead in quantum computing patent filings (see graphic below), though China is working to close that gap each year.[8]

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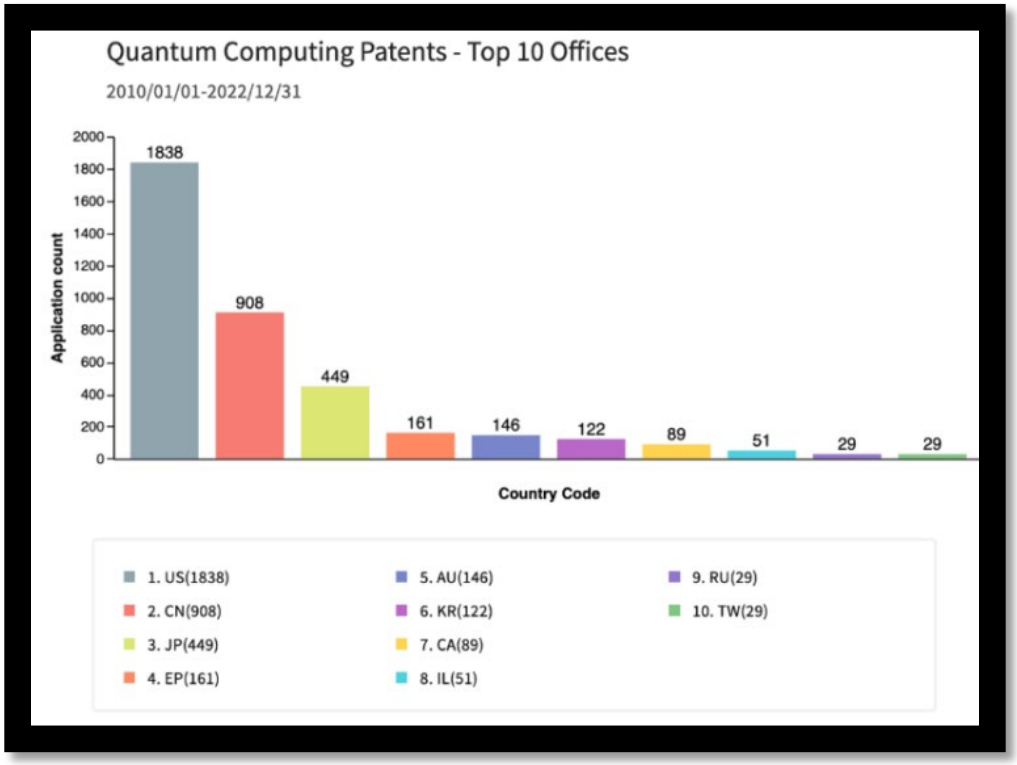
[2] Caltech Science Exchange, How Will Quantum Technologies Change Cryptography?, available at https://scienceexchange.caltech.edu/topics/quantum-science-explained/quantum-cryptography
[3] IEEE Spectrum, Quantum Computers Getting Smarter at Simulating Chemistry, available at https://spectrum.ieee.org/quantum-chemistry-largest
[4] MIT, Inspiring Quantum Data Analysts, available at https://hdsr.mitpress.mit.edu/pub/eyywouav/release/3
[5] Department of Energy, DOE Explains…Quantum Computing, available at https://www.energy.gov/science/doe-explainsquantum-computing
[6] Business of Business, Who's winning the quantum computing race? China and the U.S. are neck and neck, February 23, 2022, available at https://www.businessofbusiness.com/articles/whos-winning-the-quantum-computing-race-china-and-the-us-are-neck-and-neck/
[7] Tracxn, Quantum Computing Startups in the United States, March 5, 2023, available at https://tracxn.com/explore/Quantum-Computing-Startups-in-United-States
[8] QED-C, Quantum Patent Trends Update: 2022, February 13, 2023, available at https://quantumconsortium.org/blog/quantum-patent-trends-update-2022/



Quantum Sensing: Quantum sensors exploit the fundamental properties of atoms and light to make measurements of the world.[9] The U.S. Army has developed sensors, that can detect communications signals over the entire radio frequency spectrum.[10] This sensor enables new warfighter capabilities by dramatically improving the sensitivity of communications detection devices and eliminating the need for multiple communications receivers on weapons platforms that are susceptible to damage or destruction on the battlefield. More work on the development, hardening, and miniaturization of these sensors is needed to fully realize the potential of this specific use case, but it demonstrates how quantum technologies are already being deployed.

Quantum sensors are also making waves in the biomedical industry. The accuracy and atomic length scale of quantum sensors enables them to detect even microscopic phenomena.[11] From detecting changes in electromagnetic fields, which can be used to accurately image brain activity, to microscopic measurement and imaging, which can be used for highly technical single-cell spectroscopy, quantum sensors have vast unrealized potential to improve health care practices.[12]

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[9] Nature, Quantum sensors will start a revolution — if we deploy them right, May 24, 2023, available at https://www.nature.com/articles/d41586-023-01663-0#:~:text=Quantum%20sensors%20exploit%20the%20fundamental,for%20making%20a%20quantum%20computer.
[10] U.S. Army, Army scientists create innovative quantum sensor, March 19, 2020, available at https://www.army.mil/article/233809/army_scientists_create_innovative_quantum_sensor
[11] Aslam, N., Zhou, H., Urbach, E.K. *et al.* Quantum sensors for biomedical applications, February 3, 2023, available at https://www.nature.com/articles/s42254-023-00558-3#citeas
[12] Id.

Quantum Networking and Communications: Quantum networks use the quantum properties of photons to encode information. These properties enable the service of communication, but they also make quantum-based communications uniquely secure.[13] It would also enable communications across vast distances. Entanglement allows two measured units to behave in predictable ways regardless of the distance between the two units. Quantum network repeaters are being developed by the Department of Energy and others that use entanglement to extend the range of quantum networks.[14]

The Global Race for Quantum Leadership

Summary: Quantum technologies will be transformative across the scientific, economic, and defense realms. For that reason, there is a global race among great powers to develop operational quantum platforms across a variety of applications. The United States has retained its global leadership in the theoretical physics that underpins quantum computing and related technologies, but adversarial nations like China have taken the lead in developing quantum applications and understanding the programming of such applications. China is investing in applied quantum science at double what the rest of the world is, *combined.*

China: China has identified quantum capabilities as one of several mission-critical technologies for its economic and national security. In 2016, China launched a massive quantum initiative with the stated goal of surpassing the United States by 2030. In the nation's 14th five-year plan, China announced it would fund an estimated $15.3 billion in quantum research and development activities.[15] Since that time, China has claimed major breakthroughs in quantum capabilities, including allegedly developing computing platforms that can outstrip U.S. leaders like Google.[16] China has made other claims that it has reached major milestones in defense applications of quantum science that have not been verified or peer reviewed, but the acceleration in Chinese quantum claims highlights the nation's interest in gaining an advantage over its challengers.

Russia: Russia recently established its own National Quantum Laboratory under Rosatom.[17] Russia's stated objective is to reach a 100-qubit quantum computer by 2024. Russia also incorporated quantum technologies into its strategic technology road maps before the war in Ukraine. Despite early successes, such as developing low-qubit quantum computers, sanctions on Russia and the resource draw for the Ukraine war are likely to have hindered rapid development in Russia's quantum capabilities. The war has also impacted global supply chains, such as limiting the availability of helium.[18]

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[13] Department of Energy, DOE Explains…Quantum Networks, available at https://www.energy.gov/science/doe-explainsquantum-networks
[14] Id.
[15] Mateusz Masiowski et al., "Quantum Computing Funding Remains Strong, But Talent Gap Raises Concern," McKinsey Digital, June 2022, https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/quantum-computing-funding-remains-strong-but-talent-gap-raises-concern
[16] Dashveenjit Kaur, "China Has Quantum Computers that Are 1 Million Times More Powerful than Google's," T_HQ Technology and Business, October 28, 2021, https://techhq.com/2021/10/china-has-quantum-computers-that-are-a-million-times-more-powerful-than-googles/
[17] Rosatom, Russia sets up National Quantum Lab, November 26, 2020, available at https://rosatom.ru/en/press-centre/news/russia-sets-up-national-quantum-lab/
[18] Matt Swayne, "How Will the Ukraine–Russia Crisis Affect Quantum?" The Quantum Insider, March 10, 2022, https://thequantuminsider.com/2022/03/10/how-will-the-ukraine-russia-crisis-affect-quantum/

Europe: The European Union has launched a 10-year research initiative, called Quantum Flagship, with an approximate $1.06 billion budget.[19] This initiative will fund research in quantum computing, simulation, communications, basic quantum physics, quantum metrology, and quantum sensing. It also includes efforts to modernize communications networks to use quantum key distribution cryptography.[20] Several member states have also announced joint ventures, such as the quantum communication infrastructure network. European space interests in France and Austria are coordinating on projects to develop operational quantum communications satellites.[21] Germany itself announced a more than $2 billion investment in quantum science, and multiple leading German corporations are working as part of a consortia to develop quantum capabilities for industrial applications.[22]

Legislative History and Government's Role in Quantum Science

National Quantum Initiative Act: The National Quantum Initiative Act[23] (NQIA) was signed into law by President Trump on December 21, 2018 "to accelerate quantum research and development for the economic and national security of the United States." The NQIA authorizes the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the Department of Energy (DOE) to strengthen QIS Programs, Centers, and Consortia. The NQIA also calls for a coordinated approach to QIS Research and Development (R&D) efforts across the United States Government, including the civilian, defense, and intelligence sectors.

To guide these actions, the NQIA legislates some responsibilities for the National Science and Technology Council (NSTC) Subcommittee on Quantum Information Science (SCQIS), the NSTC Subcommittee on the Economic and Security Implications of Quantum Science (ESIX), the National Quantum Coordination Office (NQCO), and the National Quantum Initiative Advisory Committee (NQIAC).

Recognizing that QIS technologies have commercial and defense applications, additional authorization for QIS R&D is legislated by the National Defense Authorization Act (NDAA). Civilian, defense, and intelligence agencies all have a long history of investments in QIS and have a stake in future QIS discoveries and technology development. The National Quantum Initiative now provides an overarching framework to strengthen and coordinate QIS R&D activities across U.S. Departments and Agencies, private sector industry, and the academic community.[24]

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[19] Quantum Flagship, Introduction to the Quantum Flagship, available at https://qt.eu/about-quantum-flagship/
[20] News release, "The Launch of the Quantum Flagship," Quantum Flagship, October 29, 2018, https://qt.eu/about-quantum-flagship/newsroom/quantum-flagship-launch-press-release/
[21] Keith Cowing, "Thales Alenia Space and Partners Sign Contract With European Space Agency for TeQuantS Quantum Satellite Communications Project," SpaceRef, January 23, 2023, https://spaceref.com/newspace-and-tech/thales-alenia-space-and-partners-sign-contract-with-european-space-agency-for-tequants-quantum-satellite-communications-project/
[22] "Germany to Support Quantum Computing with 2 Billion Euros," Reuters, May 11, 2021, https://www.reuters.com/article/us-germany-quantumcomputer-idUSKBN2CS0W9
[23] Public Law 115-368, National Quantum Initiative Act, available at https://www.congress.gov/115/plaws/publ368/PLAW-115publ368.pdf
[24] https://www.quantum.gov/about/

NDAA and Defense Legislation in Quantum: The National Defense Authorization Act (NDAA) for FY 2019[25] and the NDAA for FY 2020[26] direct the Department of Defense (DOD) to carry out and support quantum information science and technology research and development. The NDAA authorizes the DOD to increase the technology readiness level of quantum information science technologies under development in the United States, support the development of a quantum information science and technology workforce, and enhance awareness of quantum information science and technology.[27] The NDAA provides authorization to coordinate all quantum information science and technology research and development within the DOD, including through consultation with the NQCO, the SCQIS, and other appropriate Federal entities and private sector entities.

The NDAA for FY 2020 further authorizes the establishment of Quantum Information Science Research Centers.[28] The NDAA for FY 2022 amended the National Quantum Initiative Act to include the NSTC Subcommittee on the Economic and Security Implications of Quantum Science (ESIX).[29]

CHIPS and Science Act: The CHIPS and Science Act of 2022[30] amended the NQIA to authorize R&D in quantum networking infrastructure, the development of standards in quantum networking and communication, the establishment of a Quantum User Expansion for Science and Technology (QUEST) program to facilitate a competitive, merit-reviewed base process for access to U.S.-based quantum computing resources for research purposes, and the integration of quantum information science and engineering into the STEM curriculum at all education levels. It also explicitly includes quantum information science in the new NSF Directorate for Technology, Innovation, and Partnerships, as well as in existing Federal scholarship programs.[31]

Quantum Coordinating Bodies: The National Quantum Initiative is carried out by federal agencies, and the NQIA, as amended, calls for interagency coordination through the National Science and Technology Council Subcommittee on Quantum Information Science and the NSTC Subcommittee on Economic and Security Implications of Quantum Science.

The NQIA also established the formation of the National Quantum Initiative Advisory Committee to provide independent assessments and recommendations about the National Quantum Initiative. The NQIAC consists of 15 individuals across government, academia, and industry appointed by the President.[32] On May 19, 2023, the NQIAC convened to present recommendations to Congress for the next five years of the National Quantum initiative.[33] The NQIAC made the following overarching recommendations:

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[25] Public Law 115-232, John S. McCain National Defense Authorization Act for Fiscal Year 2019, available at https://www.congress.gov/115/bills/hr5515/BILLS-115hr5515enr.pdf
[26] Public Law 116-92, National Defense Authorization Act for Fiscal Year 2020, available at https://www.congress.gov/116/plaws/publ92/PLAW-116publ92.pdf
[27] Id.
[28] Id.
[29] Id.
[30] Public Law 117-168, Chips and Science Act, available at https://www.congress.gov/117/plaws/publ167/PLAW-117publ167.pdf
[31] Id.
[32] https://www.quantum.gov/about/nqiac/
[33] Department of Energy, National Quantum Initiative Advisory Committee, available at https://www.quantum.gov/wp-content/uploads/2023/05/NQIAC-Slides-2023-05-19-Draft.pdf

- To ensure U.S. leadership in QIST, the NQIA should be reauthorized and expanded. All authorized QIST programs in the NQIA, the CHIPS and Science Act, and other relevant legislation should be funded at the authorized levels.

- To ensure that the United States leads in QIST discovery, innovation, and impact, efforts should be increased to attract, educate, and develop U.S. scientists and engineers in QIST-related fields, improve and accelerate pathways for foreign QIST talent to live and work in the United States, and increase support for research collaboration with partner nations.

  To safeguard the security and competitiveness of U.S. advances in QIST, the United States should develop policies that thoughtfully promote and protect U.S. leadership in QIST; expand domestic center-scale and single principal investigator QIST research activities and infrastructure; and evaluate and improve the reliability of global supply chains for QIST.

- To realize the potential of QIST for society, the NQI must accelerate the development of valuable technologies. This goal will require new programs in engineering research and systems integration that will enable a virtuous cycle of maturation and scaling of quantum systems to useful applications through multisector partnerships and engagement with potential end-users.

Finally, the NQIA established the National Quantum Coordination Office to oversee the interagency coordination of the NQI Program, carry out the daily activities needed for coordinating and supporting the NQI, and provide technical and administrative support to the committees.[34]

National Institute of Standards and Technology: NIST is one of the world's leaders in quantum information research and its expertise in measurement science, quantum physics, and information technology has produced discoveries and breakthroughs since the birth of the field in the mid-1990s. NIST researchers created the first component of a quantum computer, known as a quantum logic gate. They have developed many of the world's best single-photon detectors and transmitters for sending and receiving quantum data. They have made quantum logic clocks, which could potentially provide the world's best timekeeping and lead to new discoveries in physics, such as the detection of dark matter. NIST is also actively developing post-quantum encryption algorithms.

Some of the most fundamental quantum research in the world is carried out in partnerships between NIST and top universities, such as JILA[35], the Joint Quantum Institute (JQI)[36] and the Joint Center for Quantum Information and Computer Science (QuICS).[37] Scientists in these institutes leverage the combined resources of the partners to advance research in the control of atoms and molecules and development of ultra-fast lasers capable of manipulating states of matter. The discoveries that have been made in these institutes continue to be applied to meeting new measurement challenges, such as the development of the world's best atomic clocks and lasers.

[34] https://www.quantum.gov/about/
[35] https://jila.colorado.edu/
[36] https://jqi.umd.edu/
[37] https://quics.umd.edu/

An emerging research focus at NIST is understanding the potential for quantum-based technology to transform security, computing, and communications, and to develop the measurement and standards infrastructure necessary to exploit this potential. NIST is also developing the technology to harness the power of quantum computing in the everyday world through nanotechnology.[38]

The President's Budget Request for FY24 includes $220.2 million for Fundamental Measurement, Quantum Science, and Measurement Dissemination, which captures NIST's quantum programs.[39] This includes a $5 million increase over FY23 to expand partnerships with industry to enhance translational work to promote economies of scale for practical quantum applications.

Quantum Economic Development Consortium (QED-C): NIST founded and supports the QED-C, which was prescribed by the National Quantum initiative Act. The QED-C aims to expand U.S. leadership in global quantum research and development and the emerging quantum industry in computing, communications and sensing. The QED-C is run by SRI International, a nonprofit, independent R&D center headquartered in Menlo Park, California.[40] Corporations, academic and research institutions, and quantum industry supporting businesses across the supply chain are eligible for membership.[41] QED-C convenes both government and private-sector member organizations to:

- Determine workforce needs essential to the development of quantum technologies;
- Provide efficient public-private sector coordination;
- Identify technology solutions for filling gaps in research or infrastructure;
- Highlight use cases and grand challenges to accelerate development efforts; and
- Foster sharing of intellectual property, efficient supply chains, technology forecasting and quantum literacy.

QED-C members collaborate on precompetitive R&D such as device design and prototyping, increase efficiencies while sharing resources, and leverage private capital with government funding. The intent of facilitating these activities is to enable access to quantum engineering capabilities to efficiently create, test, and validate potential technology platforms and processes.

National Science Foundation: NSF has a long history of investment in research that has helped lay the groundwork for the quantum-based technologies that are on the horizon for rapid development over the next few years. At the same time, industry is beginning to make its own investments as the first new products are identified and brought to market. This creates a need for a workforce trained in a spectrum of disciplines to develop the supply chain and turn new discoveries into practice.[42]

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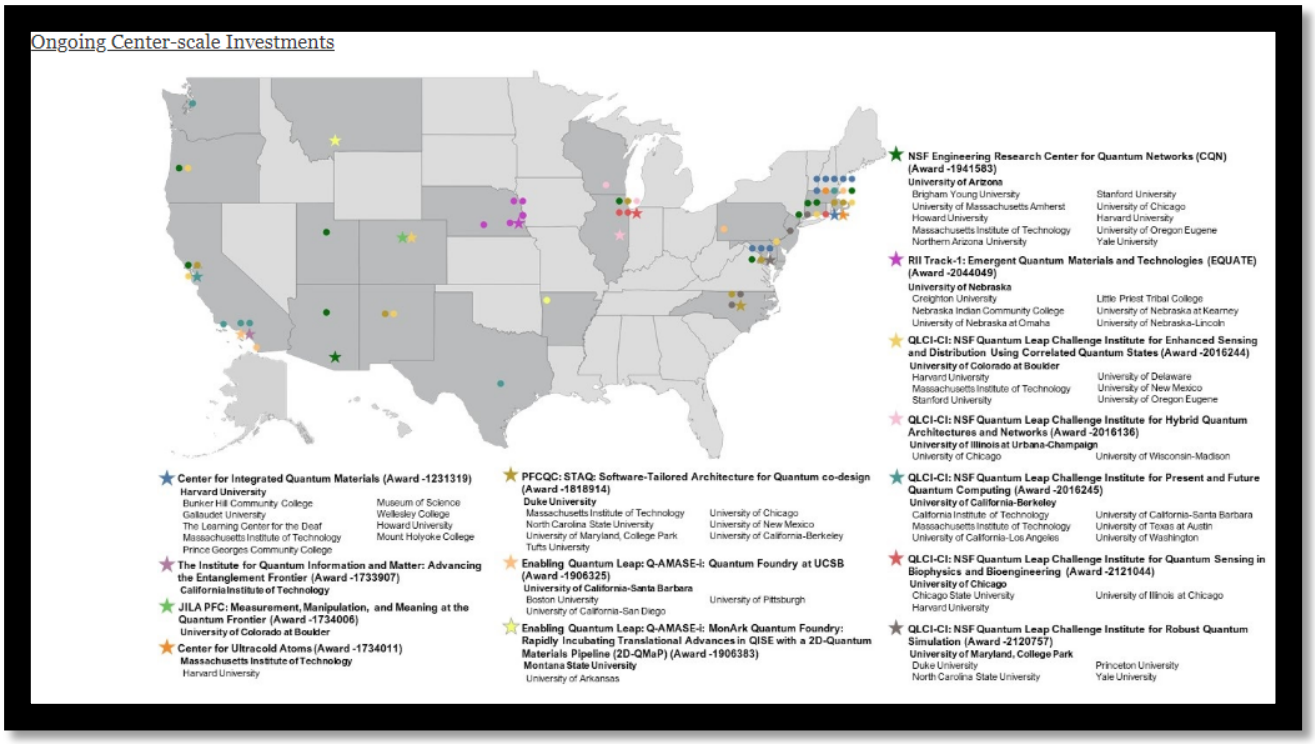
[38] https://www.nist.gov/quantum-information-science
[39] National Institute of Standards and Technology Fiscal Year 2024 Budget Submission to Congress, available at https://www.commerce.gov/sites/default/files/2023-03/NIST-NTIS-FY2024-Congressional-Budget-Submission.pdf
[40] National Institute of Standards and Technology, NIST Launches Consortium to Support Development of Quantum Industry, available at https://www.nist.gov/news-events/news/2018/09/nist-launches-consortium-support-development-quantum-industry
[41] https://quantumconsortium.org/membership/
[42] https://www.nsf.gov/mps/quantum/quantum_research_at_nsf.jsp



NSF is committed to continuing to foster quantum-based research in the following three ways:

- **Advancing Quantum Frontiers:** Frontier knowledge generated through NSF-supported discoveries will open new vistas and opportunities in the quantum arena, such as new materials, circuits, and algorithms that enable novel quantum and post-quantum applications including artificial photosynthesis, highly sensitive radiation detectors, and many others not currently foreseen.[43]

- **Multidisciplinary Collaboration:** NSF will capitalize on the full breadth of scientific and engineering areas that it funds to bring together researchers from multiple disciplines to address the fundamental science and engineering questions that will accelerate progress in all areas of quantum applications, from sensing to communication to computing to simulation.[44]

- **Workforce Development:** Through its support for research and education at universities, NSF investments will build capacity by training the workforce that is essential to progress and commercialization in this rapidly expanding field of emerging technology.[45]

The President's Budget Request for FY24 includes $332.67 million in QIS funding for NSF, a nearly 25% increase over FY23 levels.[46]

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[43] https://www.nsf.gov/mps/quantum/quantum_research_at_nsf.jsp#Quantum
[44] Id.
[45] Id.
[46] https://nsf-gov-resources.nsf.gov/2023-03/NSF%20FY24%20CJ_Entire%20Rollup-revised.pdf?VersionId=piT6beLuOyugsHnEnBgrvdTknW8564PZ

Investments by Program Component Area

QIS Funding by Program Component Area

(Dollars in Millions)

	FY 2022 Actual[1]	FY 2023 Estimate Base	Disaster Relief Supplemental Base	Disaster Relief Supplemental CHIPS and Science	FY 2023 Estimate Total	FY 2024 Request
Foundational Quantum Info. Science Advances	$185.10	$122.67	$0.60	$0.57	$123.84	$138.45
Quantum Computing	41.85	39.71	2.25	2.15	44.11	55.41
Quantum Networks and Communications	35.35	30.25	2.17	2.08	34.50	41.65
Quantum Sensing and Metrology	29.25	28.09	0.73	0.70	29.52	37.42
Future Applications	39.06	28.14	3.16	3.02	34.32	46.45
Risk Mitigation	4.52	3.63	0.38	0.36	4.37	6.60
Supporting Technology	12.65	4.64	0.31	0.30	5.25	6.69
Total	**$347.79**	**$257.13**	**$9.60**	**$9.18**	**$275.91**	**$332.67**

[1] FY 2022 Actual may be greater than future fiscal years due to the receipt of more meritorious proposals than expected.

NASA: While not an official member of NQIA, NASA does have some representation on the various advisory committees and has made investments in quantum RD&T. NASA established the Quantum Science and Technology Laboratories under its Jet Propulsion Laboratory to support the research and development of advanced technologies and precision instruments enabled by quantum mechanical and photonic processes. Basic research activities include laser cooling and trapping of atomic particles, ultra cold atom physics, nonlinear optics and quantum optics, frequency control and precision measurements.[47] The focus areas are high performance atomic clocks, atom interferometer sensors, microresonator devices, and laser interferometers, as well as their applications for fundamental physics measurements in space.

NASA also runs the Quantum Artificial Intelligence Laboratory (QuAIL) under its Intelligent Systems Division.[48] QuAIL is the space agency's hub for assessing the potential of quantum computers to impact computational challenges faced by the agency in the decades to come. NASA's QuAIL team aims to demonstrate that quantum computing and quantum algorithms may someday dramatically improve the agency's ability to address difficult optimization and machine learning problems arising in NASA's aeronautics, Earth and space sciences, and space exploration missions.

Department of Energy: DOE's Office of Science supports robust Quantum Information Science (QIS) research and development activities across its core program areas. In fiscal year 2023, DOE received a total of $288 million for QIS initiatives, which includes support for its five National Quantum Information Science Research Centers (NQISRCs), as authorized in the NQIA.[49,50]

Some Office of Science research program activities include:

[47] https://scienceandtechnology.jpl.nasa.gov/quantum-sciences-and-technology-laboratories
[48] https://www.nasa.gov/content/nasa-quantum-artificial-intelligence-laboratory-quail
[49] https://www.energy.gov/sites/default/files/2023-03/doe-fy-2024-budget-vol-5-science-v3.pdf
[50] PUBL368.PS (congress.gov)

- Advanced Scientific Computing Research (ASCR): driving innovation in quantum computing by developing new algorithms and by supporting the development of quantum testbeds.
- Basic Energy Sciences (BES): leveraging the BES Nanoscale Science Research Centers to advance materials and chemistry research that will help tackle high-priority QIS challenges in areas like quantum coherence.
- High Energy Physics (HEP): analyzing quantum sensors and related opportunities for new areas of HEP research.
- Nuclear Physics (NP): exploring quantum chromodynamics, nuclei, nuclear astrophysics, and fundamental nuclear symmetries.
- Fusion Energy Sciences (FES): developing quantum sensors that are uniquely capable of monitoring fusion plasma and providing new data for researchers.
- Biological and Environmental Research (BER): supporting QIS applications in bioimaging.

As a part of the NQIA, DOE was tasked with creating up to 5 National QIS Research Centers which have unique missions and capabilities that will help maintain U.S. leadership in QIS.

Q-NEXT: Next Generation Quantum Science and Engineering: Based at Argonne National Laboratory, Q-NEXT is focused on quantum communications and the ability to reliably control, store, and transmit quantum information across long distances. This work will be instrumental in the development of more complex quantum networks in the future.[51]

C^2QA: Co-design Center for Quantum Advantage: Located at Brookhaven National Laboratory, C^2QA is conducting basic physics research that will allow quantum computers to be more accurate and efficient. This research into both materials and software simultaneously will allow for quantum computers to be developed much more quickly.[52]

SQMS: Superconducting Quantum Materials and Systems Center: Situated at Fermi National Accelerator Laboratory, SQMS is working to develop quantum devices to test and improve their capabilities. This work is unique to the high energy physics research conducted at Fermi where they are leveraging superconducting radio-frequency cavities to increase the knowledge of how these systems operate.[53]

QSA: Quantum Systems Accelerator: Lawrence Berkeley National Laboratory is home to QSA which is working to develop algorithms that can be used to further optimize quantum systems. This research on basic quantum systems will accelerate the development and eventual commercialization of the technology.[54]

QSC: The Quantum Science Center: At Oak Ridge National Laboratory, QSC is researching key challenges for QIS in controllability and the maintainability of quantum states. The center is also focused on the workforce and creating a pipeline of skilled individuals that will be needed as the field develops.[55]

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[51] About Q-NEXT - Q-NEXT
[52] C2QA | Co-design Center for Quantum Advantage (bnl.gov)
[53] SQMS Center (fnal.gov)
[54] QSA: Quantum Systems Accelerator (lbl.gov)
[55] Home - Quantum Science Center (qscience.org)

Department of Defense: The Department of Defense engages in basic research, defined as the 'systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind.' DOD has supported fundamental QIS research for three decades, and continues to invest in basic QIS R&D activities via several DOD offices, agencies, and laboratories. These include: the Office of the Under Secretary of Defense for Research and Engineering (OUSDRE); the Defense Advanced Projects Agency (DARPA); the Army Research Laboratory (ARL), the Army Research Office (ARO); the Naval Research Laboratory (NRL); the Office of Naval Research (ONR), the Air Force Research Laboratory (AFRL); and the Air Force Office of Sponsored Research (AFOSR).

Further Reading:

CRS:

1. CRS - Quantum Information Science: Congressional Activity and Federal Policy Recommendations
2. CRS – Defense Primer: Quantum Technology
3. CRS - Preparing Secrets for a Post-Quantum World – National Security Memorandum 10
4. CRS – Quantum Information Science: Applications, Global Research and Development, and Policy Considerations

Competitiveness and National Security:

5. Heritage Foundation - Beating China in the Race for Quantum Supremacy
6. QED-C – Assessing the Needs of the Quantum Industry
7. QED-C – Challenges and Opportunities for Securing a Robust US Quantum Computing Supply Chain
8. AEI – Quantum Computing: A National Security Primer
9. Center for Security and Emerging Technology – How to Ensure the U.S.'s Quantum Future

Quantum Basics:

10. Caltech – What is Quantum Computing? [video]
11. Argonne National Laboratory – Science 101: What is Quantum? [video]
12. Readwrite – What Quantum Computing Will Mean for the Future Artificial Intelligence
13. QED-C – Quantum Sensing Use Cases

Strategic Reports:

14. NSTC – A National Strategic Overview for Quantum Information Science
15. NSTC – A Coordinated Approach to Quantum Networking Research
16. NSTC – Quantum Frontiers
17. NSTC – The Role of International Talent in Quantum Information Science
18. NSTC – Quantum Information Science and Technology Workforce Development National Strategic Plan
19. SQIS – Bringing Quantum Sensors to Fruition
20. Executive Office of the President – National Security Memorandum on Quantum-Resistant Cryptography
21. Department of Defense – National Defense Science and Technology Strategy