National Quantum Initiative—Action Plan

This implementation proposal for a National Quantum Initiative (NQI) follows the June 2017 white paper, "Call for a National Quantum Initiative," produced by a collective of academics, industry experts and professional societies*. The NQI was then supported during an October 2017 hearing by the U.S. House Committee on Science, Space and Technology entitled "American Leadership in Quantum Technology," where testimony was presented demonstrating that a NQI will ensure scientific leadership and economic and national security.

Quantum technology: solving hard problems and securing information

There are many complex problems in science and society that will never be solved using conventional computers and information technology. Quantum technology (QT) can store and process otherwise inaccessible amounts of data, owing to the unique principles underlying quantum systems. Unlike the 0s and 1s in conventional computers, *quantum bits* can represent both values 0 and 1 simultaneously, taking on definite values only when observed. The power of a quantum computer doubles with each added quantum bit, leading to many potential applications that are impossible using conventional technology:

- **Optimization over huge data sets**. Quantum computers will be able to sort rapidly through data sets that are too large to ever be stored on conventional devices, such as real-time video of the entire surface of the earth. Quantum programs can potentially store, optimize, or search such databases very rapidly, with potential uses in autonomous vehicle navigation, weather prediction, machine learning, economic market analysis, code-breaking, and logistics including energy and transportation systems.
- **Design of new materials and molecular functions**. Quantum computers can be programmed to simulate the behavior of complex molecules and materials beyond the reach of conventional computers. This will usher the discovery of new substances with exotic electrical/mechanical properties, designer molecules for efficient drug activity, and efficient materials for the conversion of energy between light and electricity.
- **Secure communications.** Quantum bits change when they are observed, meaning it is possible to send information while knowing whether or not it is secret. Quantum communication can also allow secure communication between multiple (possibly untrusted) parties for optimal decision making, and for interconnecting large-scale quantum computers via a quantum internet.
- **Quantum sensing and metrology**. Quantum technologies enable a new generation of atomic clocks and ultra-precise sensors with applications ranging from natural resource exploration and biomedical diagnostics to navigation in a GPS-blind environment.

Quantum technology will also usher great scientific opportunities. Just as the LIGO gravitational wave detector enables scientists to peer into the cosmos with new eyes, QT opens windows into a realm governed by the counterintuitive laws of quantum physics. More than being the basis for new, essential technologies, QT will reveal ever deeper understanding into the nature of the physical world. QT will also advance fundamental science by providing computing power to simulate a host of intractable problems from nuclear physics and neuroscience to other complex interacting systems.

The next few years will see quantum computers with over 100 quantum bits, each of which would eclipse the storage capacity of all hard drives in the world. The NQI will build upon this quantum technology and exploit its power for applications that will propel the U.S. economy into the future. The United States must retain its leadership in this scientific and technological frontier, in the face of large concentrated international QT efforts elsewhere, including China (estimated $10B), E.U. ($1.2B), and UK ($460M).

Creating the QT workforce

A key challenge in the development of QT in the U.S. is the workforce gap between university research efforts and industrial development. University laboratories cannot properly engineer QT, given their central mission of education and research, and lack of dedicated engineering teams. Industrial QT efforts just underway in the U.S. will produce first-generation quantum technologies. However, there is a limited engineering workforce to fabricate and test this new type of technology and a severe shortage of quantum software developers to bring quantum computers and devices to users. The NQI will become a proving ground for academic, government, and industrial scientists and engineers to pool their resources for technology developments and to provide a QT talent pool for the future development of quantum computers, quantum communication networks, and quantum sensors.

The need for major QT facilities and infrastructure

Quantum information science, the basis of all QT, is moving into a new era that demands a NQI with an added component not present in the current research infrastructure. Quantum information science has progressed to a stage where many research needs outpace capabilities of individual laboratories. Just like the large shared telescopes in astronomy and the sophisticated shared fabrication facilities in nanotechnology, quantum information science requires large-scale facilities and supporting infrastructure. Such facilities will provide stable, sustainable scientific and engineering platforms for QT and software prototyping. Professional staff will co-develop and maintain the technical infrastructure enabling the basic science and technology transfer activities of the users, both on-site and remote. With these, U.S. science will push the frontiers of knowledge and innovation the farthest and fastest.

Implementation plan

The operational goals of the NQI are to (a) Engage and produce a world-leading industrial QT workforce, (b) Engineer, industrialize, and automate QT including quantum computers, communication systems and quantum sensors, (c) Provide access to the emerging quantum computer systems, (d) Develop conventional technology and intellectual property (IP) needed to support and enable QT, (e) Produce quantum software and new applications of QT, and (f) Continue the fundamental research needed to support these NQI goals, and arising from the capabilities of QT.

The NQI will be anchored by three to six new facilities called **Quantum Innovation Laboratories** (QILabs), along with a **Quantum Research Network** (QRNet) and a **Quantum Computing Access Program** (QCAP). Each QILab will be located at a central facility in the U.S. and have a distinct and focused research and development mission and may include satellite QILab participants and facilities as appropriate. The QILabs will provide sophisticated, well-engineered experimental platforms for developing and testing QT and performing state-of-the-art scientific studies. The QILabs will supplement existing technology transfer and research programs at government agencies, which will also continue to support fundamental research in quantum science necessary for QT innovation. QRNet will consist of a web of autonomous research groups distributed throughout the country at academic, government, and industrial sites. QCAP will ensure leading American researchers have access to quantum computing capabilities.

Each **QILab** and its satellites will focus on research and development of a particular family of quantum technologies, or a suite of closely related technologies, including supporting technology, control systems, software and user interfaces, and theoretical co-design of applications or algorithms mapped to the technology. For example, QILab thrusts in solid-state superconducting and semiconductor quantum systems would fabricate quantum computers with more than 100 quantum bits, develop and optimize quantum materials, advance cryogenic packaging and fast electronic control systems, and mitigate noise from material defects. QILab activity in isolated atomic systems including trapped ions and neutral atoms would develop quantum computers with more than 100 quantum bits, engineered with external optical control systems to quantum entangle and manipulate large-scale atomic systems. QILab technology may feature the engineering of photonic quantum networks and supporting technologies for enabling long-distance (greater than 100 km) transmission of quantum information through a quantum internet, for linking nodes of a distributed quantum computer operating with more than 100 quantum bits, and for distributed sensing applications. QILab efforts may involve quantum-enabled sensing applications including subsurface imaging, biomedical imaging, atomic clocks and GPS-free navigation.

The **QRNet** program will support fundamental research of QT by funding individual efforts to investigate and collaborate with QILab technologies, combine different QT for hybrid quantum systems, and uncover promising quantum systems for future quantum bit realization and QT development. QRNet will also investigate new quantum algorithms and its enabling software to drive existing QT, with potential applications in the areas of quantum chemistry and materials development, artificial intelligence and machine learning, and optimization.

The **QCAP** will support the activities of the QILab and QRNet programs by providing access to the most advanced American quantum computing systems and simulators. The most advanced commercially available American-made quantum computing systems will be made available via secure cloud access to all QILab and QRNet projects, applicable advanced scientific computing projects, and U.S. government researchers. The facilities will include technology from multiple American vendors and at least two different underlying quantum computing hardware technologies. Additionally, the QCAP should leverage high-performance computing resources to allow application developers to simulate aspects of the quantum algorithms and hardware in the QILab and QRNet programs.

NQI budget and administration

The QILab, QRNet and QCAP components of NQI will be administered through the civilian agencies NSF, NIST, and DOE with an overall budget of $800 million over an initial 5-year phase. This includes a $500 million budget for the QILabs, with some funded at higher levels around $25 million per year, while others will have lower funding needs. The QRNet will be funded at $200 million, or $40 million per year, and the QCAP will be funded at a level of $100 million over five years.

Each QILab will involve additional in-kind support, including facility space, research infrastructure, and scientific and administrative personnel from the host institutions. Joint research-and-teaching programs will be provided by satellite partner universities, supported by grants from the QILabs or other mechanisms. Funds will also be made available by QILabs to support research by non-university off-site groups contributing research relevant to the QILabs goals. Industrial members of the QILabs will embed industrial researchers and engineers for termed periods, with the goal of these industrial employees returning with expertise in quantum technology. Industrial stakeholders will also provide student fellowships and internships at the QILab host universities or laboratories, with opportunities for these researchers to intern both at the QILabs and at the engaged industrial partner locations. Intellectual property invented at the QILabs will be shared among the participants, with each QILab determining an IP plan suitable for its performers. In addition, support from the Small Business Innovative Research and Small Business Technology Transfer Research programs will be directed toward supporting the Initiative.

QILabs/QRNet/QCAP will be administered and funded in a coordinated fashion by an appropriate grouping of programs within NSF, NIST, and DOE, to be decided jointly by those agencies, and informally advised by QT experts selected by NSF, NIST, DOE, and the Department of Defense (DOD) and Intelligence agencies, accounting for recommendations by industry. These agencies will coordinate their existing programs in underlying quantum science and technology with the QILabs. The QILab and QRNet performers will be selected by the above agencies based on existing solicitation and evaluation procedures. Each QILab will be led by a scientific and administrative director, who will coordinate the operation of the QILab with the above agencies.

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* The original convener of the NQI collective is the National Photonics Initiative (NPI), a collaborative alliance among industry, academia and government formed in 2013 to raise awareness of and increase investment in the fields of optics and photonics most critical to maintaining U.S. economic competitiveness and national security. The initiative is led by The Optical Society (OSA) and SPIE, the International Society for Optics and Photonics (SPIE), and support by top scientific societies including the American Physical Society (APS), the IEEE Photonics Society and the Laser Institute of America (LIA). For more information visit www.lightourfuture.org