Quantum Industry Coalition

February 15, 2022

Via electronic submission at http://www.regulations.gov

Subject: **Comment of the Quantum Industry Coalition Regarding the National Institute of Standards and Technology Study to Advance a More Productive Tech Economy**

Reference: **86 FR 66287, Docket Number 211116-0234**

The Quantum Industry Coalition ("QIC") appreciates the opportunity to submit these comments to the National Institute of Standards and Technology ("NIST") in response to its Request for Information ("RFI") regarding its study to advance a more productive tech economy.

QIC is a group of companies dedicated to maintaining the United States' leadership in the development of quantum technologies. Our members range from start-ups to Fortune 100 companies with a variety of focuses on aspects of quantum technology, including hardware, software, and application development. We have experience working with Congress and the Administration to ensure that the United States maintains and enhances its position as the world leader in the development and commercialization of quantum technologies.

US global economic leadership depends in large part on its uniquely vibrant tech economy. As competitors challenge US leadership in an increasingly multipolar world, it is crucial that policymakers continue to cultivate an innovative US private sector and leverage it to maintain leadership. The first nation to unlock the full potential of quantum computing will attain a massive economic advantage over its competitors, because as quantum computing is commercialized, it has the potential to transform virtually every economic sector. QIC looks forward to the opportunity to serve as a resource to NIST as it works to shape policies that will ensure a thriving US tech economy and a leading US quantum computer industry.

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APPLICATIONS OF QUANTUM COMPUTING

Quantum computers will be able to solve problems intractable to classical computers, such as problems that become exponentially more difficult to solve with each additional variable. They will therefore excel at tasks requiring complex mathematical calculations or parsing through huge amounts of data. Any industry across the economy that benefits from complex modeling and simulation, large-scale data analysis, or process optimization could expect to experience a massive boost capability and efficiency. Among the commercial applications of quantum computers are:

- **Novel Drug and Material Development.** Pharmaceutical research depends on the discovery and synthesis of novel molecules to treat disease. Progress is limited by the rate at which drug developers can test new molecules. Chemists in a variety of industries are similarly limited by current molecular modeling capabilities as they work to develop novel materials that are stronger, thinner, cheaper, more flexible, or more environmentally sustainable. The development of novel drugs and materials could be hastened by simulating new molecules using quantum computers so as to understand their properties and predict their applications without having to test them in the laboratory. Such complex modeling is beyond the capacity of classical computers, but a sufficiently powerful quantum computer could lead to rapid breakthroughs in materials science or the treatment of complex diseases like Alzheimer's or Parkinson's.

- **Logistics.** Supply chains and delivery routes are so complex that even the most powerful computers fail to find the most efficient solutions, resulting in wasted time, money, and fuel. Quantum computers will excel at such optimization problems, and could quickly calculate the most efficient routes for entire fleets of delivery trucks or establish cost-effective global supply chains. Even small improvements, when applied globally across the world's largest companies, can save billions of dollars and millions of tons of CO2 emissions.

- **Energy.** Creating effective smart power grids requires processing huge amounts of data to optimally balance power loads from a variety of energy sources. Quantum computers will aid in both the planning and operation of these grids, making it easier for smart power grids to rely on renewable energy with minimal waste.

- **Agriculture.** The study of plant genetics to create crops with greater yields, climate resilience, and disease resistance is continually improving the economic output of agriculture. Progress in soil science and the development of more effective fertilizers can further improve yields. More accurate weather forecasting facilitates better decision-making, and is increasingly important as extreme weather events increase the risk of crop loss. Quantum computing's capacity to process massive amounts of data and simulate complex systems can hasten the identification of beneficial plant genes, help develop better fertilizers, and improve weather forecasting and climate modeling.

- **Financial Services.** Models predicting market behavior, assessing risk, or detecting fraud are limited by the capabilities of classical computers. With quantum computers, financial analysts could run more sophisticated models to better forecast disruptive events, predict shifts in demand and pricing, or balance risk in their portfolios.

In addition to industry-specific use cases, quantum computing could have massive, economy-wide implications:

- **Upending Cybersecurity.** Prime factorization is the basis of electronic encryption because it is all but impossible for classical computers to find the two prime factors of enormous numbers. However, prime factorization is the exactly the kind the mathematical challenge at which quantum computers excel. A sufficiently powerful quantum computer could easily decrypt most of the world's sensitive commercial and military data. If a quantum computer with this capability were developed before the large-scale deployment of quantum-resistant encryption, it could have massive implications for the balance of global geopolitical and economic power.

- **Amplifying Artificial Intelligence.** The development of artificial intelligence technologies is limited by the scalability of classical computing processing power. Hybrid quantum-classical computers being developed could enhance artificial intelligence by routing complex calculations to the quantum system while continuing to use classical computing for data storage and error correction. This potential widespread application of quantum computing to compliment artificial intelligence technology would hasten and amplify the economy-wide impacts of both.

- **Generating Scientific Breakthroughs.** Any field of science hampered by classical computing's inability analyze large amounts of data, simulate complex models, or recognize subtle patterns could see massive breakthroughs with the application of quantum computers. Widespread access to quantum computers to solve diverse sets of previously intractable scientific problems would likely result in technological developments that would yield further economic benefits.

MARKET STATUS, TRENDS, AND RISKS

Diverse Approaches to Scaling, Utility, and Commercialization

The quantum computing industry is presently focused on developing and refining architectures to 1) increase the number of qubits within a system; 2) maximize their time in coherence; 3) address the need for error correction; and 4) reduce the energy and space needed to operate the computer. Various industry leaders are racing to develop not just technical quantum supremacy - when a quantum computer is able to outperform a classical computer in a particular niche circumstance - but practical quantum supremacy.

Companies are using a wide variety of designs, materials, and methods to develop quantum computers. The result has been a diverse ecosystem with multiple approaches moving forward simultaneously and, ultimately, advancing the US quantum industry as a whole. It remains to be seen which approach will lead to the first widely-utilized quantum computer, but multiple development paths reduce the risk of over-committing to a technology that turns out to be sub-optimal. By funding a variety of approaches and not attempting to pick winners and losers in the marketplace, federal policy also facilitated this positive trend.

Useful and effective commercial quantum computers will require not just good hardware, but also strong software. Again, a variety of approaches have developed, allowing the industry and its customers to observe the costs and benefits of every avenue and use the best software tools for any specific type of problem. Additionally, there has been a proliferation of tools to help prepare users for widespread utilization. Some researchers have begun to tackle challenging scientific questions by accessing quantum computers via cloud-based platforms, and quantum simulators allow users to code, debug, and test their programs before using the real thing. Such solutions expand access to a still-maturing technology, and the industry continues to create additional tools to help future members of the quantum workforce learn and practice quantum programming.

Growing Private Investment and Interest

Many quantum computing companies are moving through the "valley of death" where they are racing to develop and mature technologies that have left the realm of laboratory research without an established cash flow. That said, in the last two years, private investment into quantum computing has grown rapidly, demonstrating the private sector's confidence in the technology's potential. In 2020, the $689 million invested into quantum computing startups by venture capitalist investors exceeded the amount invested the previous four years combined. In 2021, just 34 venture capital investments in quantum were valued at a total of $1.019 billion.[1] That same year, a five-year-old startup, IonQ, became the first quantum computing company to go public; and two more companies have since announced plans to follow. Simultaneously, many of the world's largest technology companies now have quantum computing divisions, including several QIC members. While commercial utilization is still in its infancy, major companies across a number of economic sectors have established teams to explore and prepare for fully-scaled, widely-available quantum computing. Quantum computing companies have established partnerships already with companies as diverse as BASF, Barclays, and ExxonMobil.

Foreign Competition

The first nation to develop a quantum computer with the capacity for widespread commercial utilization will be the first to capitalize on the massive economic growth it would generate. China is by far the greatest competitor to the US quantum computing industry. Though it is difficult to gauge China's position relative to the US, the rapid progress it has made since beginning its quantum technology program in 2008 suggests that, if China has not already caught up, it will do so soon. A Chinese victory in the quantum computing race represents a threat not only to the US quantum computing industry, but also US economic leadership and national security in general.

China's state-driven investments allow the country's leaders to rapidly and unilaterally pour money into favored institutions conducting promising research. In addition, US federal and private R&D programs are under constant threat of intellectual property theft orchestrated by the Chinese government, further threatening US leadership in quantum computing. Finally, China and other countries offer subsidies and otherwise compete unfairly in the global marketplace.

Supply Chain Disruptions

The specialized and cutting-edge nature of quantum computing makes it reliant on particular components and materials that are often sourced from abroad. The industry is therefore highly vulnerable to supply chain disruptions, as the ongoing COVID-19 pandemic and heightened geopolitical tensions have underscored. Further, many of the supporting technologies that enable quantum computing, such as lasers, optical fibers, and cryogenic freezers, are themselves advanced, highly specialized, and available only from foreign suppliers. To the degree that a given quantum computer architecture depends on those technologies, they constitute potential single points of failure.[2] As the economic value of quantum computers increases, maintaining access to the resources, components, and manufacturing assets that are crucial to the industry will become

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[1] See https://pitchbook.com/news/articles/quantum-computing-venture-capital-funding.
[2] See https://www.gao.gov/assets/gao-22-104422.pdf.

a matter of national concern. Improvements in supply chain risk management, including enterprise-wide adoption of decision science-based solutions, would help address this challenge in the near term. In the medium to long term, maximizing our capacity to provide key resources and components domestically - or at least via allies - will be key. On a related front, the quantum computing industry is impacted by issues affecting the broader semiconductor industry.

POLICY RECOMMENDATIONS

Accelerate Federal Quantum R&D Investments

The scale of federal investment must be globally competitive. The National Quantum Initiative Act authorized $1.2 billion for quantum technology-related activities over five years beginning in 2019. By comparison, China has publicly announced $15 billion worth of public funding for quantum computing,[3] of which roughly $10 billion was spent on the construction on the world's largest quantum technology research center.[4] Fortunately, US private-sector investment is helping close the gap - but increased federal investment is needed.

As quantum computing has "moved out of the lab," so must federal funding of the technology. The ultimate goal of US quantum policy should not only be to fund scientific research, but to facilitate the commercialization of breakthroughs into technologies that can benefit both the economy and national security. While foundational and long-term research is important, funding should also focus on real-world applications that will be available in the near and medium term. This should not extend to picking winners and losers in the marketplace, but it should include acting as a customer: buying private-sector solutions and thereby stimulating the market.

Federal quantum investments should be consistent and reliable, as funding gaps and uncertainty make institutional knowledge and talent retention more challenging, and threaten the solvency of startups that have yet to establish stable private-sector funding streams. Additional federal investments should go toward establishing reliable supplies of components and supporting technologies crucial to quantum computing. As noted above, the global semiconductor shortage in particular has generated ongoing downstream impacts on the US quantum computing industry. Further, dependence on offshore semiconductor supply chains that are susceptible to Chinese influence could limit US quantum computing development and operations, especially in a military conflict. The $52 billion in federal semiconductor R&D and manufacturing investments authorized by the CHIPS for America Act is an example of the kind of approach needed to ensure that the US quantum computing industry is secure against supply chain disruptions or attacks.

Nurture Sustained Private Sector Growth

Private sector innovation and investment provides the US with a unique advantage over China's top-down, state-driven research efforts. While US universities and National Laboratories continue to advance basic research, US quantum companies have made most of the recent breakthroughs in the application of quantum science to real-world needs. By acting as a customer for these

[3] See https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/quantum-computing-use-cases-are-getting-real-what-you-need-to-know.
[4] See https://www.scmp.com/news/china/society/article/2110563/china-building-worlds-biggest-quantum-research-facility.

commercialized quantum technologies, or by engaging in public-private partnerships with companies in the quantum fields, the US not only gains access to state-of-the-art technology with immediate applicability to defense and research priorities, but also helps grow and strengthen the US quantum economy. The US quantum industry can be the force multiplier the US government needs to beat China in the quantum race.

Within the US quantum industry are many highly innovative small businesses that are rapidly advancing the state of the art. To the extent that the government is able to provide on-ramps for those small businesses, beyond SBIR and similar programs, it will maximize its leverage of the industry overall. Contracting vehicles that are appropriately sized and not unreasonably complex are particularly valuable here.

Invest in and Broaden the Quantum Workforce

Maintaining and expanding US leadership in quantum computing research and commercialization is predicated on a strong domestic STEM workforce with accessible onramps into the field. The rapid growth of the industry has generated more job opportunities than there are qualified candidates to fill them. This gap exists at all levels of seniority, but as the technology matures, the need for technicians for maintenance and support will become increasingly important. Broadly, currently quantum science is still primarily taught at the university level as a subset of physics. Even as universities expand their quantum science offerings, these courses often remain at the graduate school level. Quantum education needs to reflect the increasingly interdisciplinary nature of quantum science, and it needs to begin earlier in order to generate the workforce that the quantum industry requires. This means developing our current educational offerings and the tools used for that education beyond their current state.

Training a strong quantum workforce calibrated to the needs of the growing industry will require reframing quantum science as an interdisciplinary field consisting of physics, engineering, and computer science. Undergraduate engineering programs should expand their curriculum to include quantum sciences classes to prepare students for the quantum workforce, with interdisciplinary quantum educations centers at universities that would assist in priming students with the variety of skills they will need. Community colleges should begin offering associates degrees to create a workforce of technicians trained to understand and maintain the components created for quantum computing, such as cryogenic systems and lasers. Programs like the National Q-12 Education Partnership should continue to receive support to bring quantum education to the K-12 level. All of these programs would benefit from cloud-accessible quantum tools, including software and hardware. Enabling schools, universities, and students of all education levels to remotely access quantum education platforms allows them to accelerate their learning and research programs even if they do not have their own systems.

As the US continues to expand its domestic quantum workforce, we should continue to educate students from abroad and especially offer incentives for post-graduation employment in the US. Established leaders in quantum science ought to be welcomed to the US to work or establish quantum businesses. However, given the economic and national security implications of quantum computing, such policies must always guard against the risks of intellectual property theft from US universities, laboratories, and companies.

Avoid Unnecessary Regulation

Premature or overly burdensome regulations have the potential to hamper innovation and disadvantage US companies relative to foreign competitors. As federal policymakers increasingly see the value of quantum leadership and, in particular, its immense implications for national security, we anticipate a greater interest in implementing export controls on quantum technology. The current export control regime burdens US quantum companies unnecessarily, while pushing innovation overseas and limiting international cooperation - to the detriment of the US. We support the creation of an export control regime that addresses national security risks without hurting US quantum competitiveness by limiting access to the global marketplace and stifling collaboration with allies. In a similar vein, Buy America provisions should balance the desire to strengthen the US industrial base with the urgent need to maintain global quantum leadership as nations race to be the first to unlock quantum computing's full potential.

Encourage Fair, Industry-Led Standard Setting

The quantum computing industry has not reached a point where standard-setting has become necessary. However, as quantum computing becomes more widely available and utilized, China is positioning itself to spearhead standard-setting efforts with the intent of gaining a competitive advantage. The policy recommendations above can help prevent this by maintaining and expanding the US quantum leadership, thereby ensuring that standards are set through voluntary, industry-led, consensus-based processes on a level playing field. NIST in particular should engage with international standard-setting bodies to ensure that all stakeholders are involved in the process and that neither China nor any other self-interested stakeholder can gain undue influence. QIC submitted a comment to NIST on this topic in December 2021, which we incorporate by reference here.[5]

AGENCIES AND JURISDICTIONS

Given the wide variety of quantum computing applications, a number of federal agencies are becoming increasingly involved in the development, regulation, and strategic application of quantum computing. The National Quantum Initiative has helped bring together the various agencies that engage with quantum computing research or policy, with NIST, the Department of Energy, and NSF in the lead. The National Quantum Coordination Office within the Office of Science and Technology Policy coordinates the quantum-related efforts of nearly two dozen federal agencies. Continued efforts to enhance coordination are warranted. A partial list of agencies and activities follows:

Department of Commerce

NIST helps set scientific and technological standards that promote US innovation and maintain international competitiveness, and will play a crucial role in brokering quantum computing standards as the technology continues to mature. The Bureau of Industry and Security (BIS) sets

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[5] Comment of the Quantum Industry Coalition Regarding the National Institute of Standards and Technology Study on People's Republic of China (PRC) Policies and Influence in the Development of International Standards for Emerging Technologies, 86 FR 60801, Docket Number 211026–0219, available at https://www.regulations.gov/comment/NIST-2021-0006-0017.

and administers the US export control regime for strategic technologies such as quantum computing.

Department of Energy

The Department oversees the nation's 17 National Laboratories and Technology Centers, eight of which have quantum R&D programs: Argonne, Brookhaven, Fermi, Lawrence Berkeley, Los Alamos, Oak Ridge, Pacific Northwest, and Sandia. Some of these National Laboratories operate quantum computing user programs and testbeds to outside researchers. Additionally, five National Quantum Information Science and Research Centers are located at National Labs: C2QA (Brookhaven), Q-NEXT (Argonne), QSA (Lawrence Berkeley), QSC (Oak Ridge), and SQMS (Fermi).

National Science Foundation (NSF)

NSF is advancing fundamental quantum research through a variety of programs, including Quantum Leap and the Quantum Leap Challenge Institutes, and the National Q-12 Education Partnership.

Department of Defense

The Department oversees substantial quantum technology R&D programs, including Defense Advanced Research Projects Agency (DARPA) and the Defense Laboratories and Centers. The Air Force Research Laboratory's Information Directorate, based in Rome, NY, has a leadership role for the Department.

Cybersecurity and Infrastructure Security Agency (CISA)

Within the Department of Homeland Security, CISA is tasked with understanding, managing, and reducing risk to cyber and physical infrastructure. CISA is currently undertaking outreach efforts to educate federal agencies and the private sector on post-quantum encryption.

National Aeronautics and Space Administration (NASA)

NASA is responsible for scientific research and technology development related to air and space. The Agency's Quantum Sciences and Technology Laboratories are undertaking a number of research activities that could develop components and methods to improve quantum computing, such as cryogenics and lasers used for putting atomic particles into superposition. The use of quantum computing to improve machine learning capabilities through hybrid quantum-classic computers is being studied at NASA's Quantum Artificial Intelligence Laboratory (QuAIL).