ADVANCING INTERNATIONAL COOPERATION IN QUANTUM INFORMATION SCIENCE AND TECHNOLOGY

A Report by the

SUBCOMMITTEE ON QUANTUM INFORMATION SCIENCE

COMMITTEE ON SCIENCE

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

AUGUST 2024

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The NSTC Subcommittee on Quantum Information Science (SCQIS) was established by the NSTC Committee on Science and codified by the National Quantum Initiative Act to coordinate Federal R&D in quantum information science and related technologies. The aim of this R&D coordination is to maintain and expand U.S. leadership in quantum information science and its applications over the next decade.

ABOUT THIS DOCUMENT

This report augments the *National Strategic Overview for Quantum Information Science* with additional policy recommendations to facilitate and realize the mutual benefits of international cooperation, which is a policy pillar of the *National Strategic Overview*. Recommendations herein were developed by the SCQIS with input from its Interagency Working Group on International Cooperation.

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ABBREVIATIONS AND ACRONYMS

AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
ARO	Army Research Office
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DOD	Department of Defense
DOC ITA	Department of Commerce International Trade Administration
DOE	Department of Energy
DOS	Department of State
ESIX	Subcommittee on Economic and Security Implications of Quantum Science
IARPA	Intelligence Advanced Research Projects Activity
ISTC	Subcommittee on International Science and Technology Coordination
IWG	Interagency Working Group
LPS	Laboratory for Physical Sciences
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NQCO	National Quantum Coordination Office
NQI	National Quantum Initiative
NRL	Naval Research Laboratory
NSA	National Security Agency
NSF	National Science Foundation
NSTC	National Science and Technology Council
ODNI	Office of the Director of National Intelligence
OMB	Office of Management and Budget
ONR	Office of Naval Research
OSTP	Office of Science and Technology Policy
QIS	Quantum Information Science
QIST	Quantum Information Science and Technology
R&D	Research and Development
S&T	Science and Technology
SCQIS	Subcommittee on Quantum Information Science

EXECUTIVE SUMMARY

Quantum information science and technology (QIST) is a critical and emerging field that could revolutionize the way information is collected, processed, and transmitted. This transformative potential is why QIST is a priority for the Biden-Harris Administration. Due to the many potential societal benefits of QIST, the field is being enthusiastically pursued around the globe. Over the past decade, numerous countries and jurisdictions have launched concentrated initiatives to strengthen their QIST enterprises. These developments have expanded global participation in QIST and have increased the importance of international collaboration. While the United States has supported international cooperation in QIST for decades, opportunities exist to adjust and strengthen its approach that will better position the Nation to both leverage international engagements and advance U.S. priorities related to QIST.

The United States should continue to focus international engagements on interactions that impart mutual benefits and are based on scientific inquiry, shared values, and economic promise. Doing so accelerates innovation; facilitates robust access to supply chains and markets; and guides the development of QIST-related principles, policies, and effective practices in the international community. International collaborations among practicing experts are particularly effective and have served as the backbone for identifying shared interests and cooperative relationships. Subject matter experts are best positioned to identify and act on opportunities, aided by existing mechanisms such as scientific workshops and the mobility of scientists and professionals.

Building on this tradition of international cooperation, there are opportunities to inform priorities, leverage additional mechanisms, establish joint research projects, pilot new approaches that catalyze discovery, and formalize collaborations where necessary, all to boost discovery and innovation. Challenges that currently complicate the development of effective international collaborations include mismatches with foreign partners on diverse topics such as technical capability, scientific and strategic priorities, and funding systems. The United States is also experiencing an increase in international requests for collaboration that could divert attention from ongoing efforts if not coordinated and prioritized effectively. This report identifies these key challenges and related gaps, and recommends actions to ensure that the United States is well-positioned to foster beneficial and nimble collaborations with a wide variety of international partners that will advance fundamental knowledge, innovation, and possibilities in QIST. These recommendations are:

1. **The U.S. Government should create dedicated and long-term mechanisms to fund international QIST collaboration and cooperation.**
2. **Agencies should enhance interagency coordination of international cooperation practices to reinforce an integrated U.S. Government-wide portfolio for international QIST engagement.**
3. **The U.S. Government should establish and track metrics for global competitiveness across QIST and its enabling technologies.**

These recommendations build upon those made in the National Science and Technology Council *National Strategic Overview for Quantum Information Science* and the report on *The Role of International Talent in Quantum Information Science,* and the National Quantum Initiative (NQI) Advisory Committee report on *Renewing the NQI.* Collectively, these actions will allow the U.S. Government, in close coordination with U.S. allies and partners, to build a global QIST landscape that reflects principles supporting scientific rigor and research integrity, freedom of inquiry, merit-based competition, openness, and transparency.

I. INTRODUCTION

Quantum information science (QIS) and technology (QIST)[1] takes advantage of quantum mechanical properties, such as superposition and entanglement, and combines them with information theory to enable new modalities of sensing, computing, communications, and networking. These new modalities can provide disruptive advantages for select applications, potentially outperforming existing classical approaches. Building on decades of American investment, the U.S. National Quantum Initiative (NQI),[2] codified in 2018 by the NQI Act,[3] authorized flagship QIST research centers and institutes, convened an industry consortium, and created several mechanisms to coordinate the NQI program. These whole-of-government efforts involving at least 23 Federal departments and agencies (hereafter, "agencies") resulted in Federal QIST spending roughly doubling from $450M in 2019 to more than $1B in 2022.[4] To accelerate American leadership in the field, the 2018 *National Strategic Overview for QIS* (*National Strategic Overview*) describes six policy pillars: science, workforce, industry, infrastructure, security, and international cooperation.[5] Subsequent strategy documents have augmented the *National Strategic Overview*, such as those on workforce and the role of international talent, all of which can be found on www.quantum.gov.[6–8] This report similarly augments the *National Strategic Overview*, in particular the international pillar, and articulates several areas for focus, including reviewing international collaborative activities, prioritizing strategic partnerships, and encouraging merit-based and transparent fundamental research and innovation systems, in order to realize the science and technology (S&T) benefits associated with the next quantum revolution.

This report discusses the current ability of the United States to fulfill these objectives. Section 2 describes the motivation for continued international collaboration in QIST, Section 3 discusses opportunities for collaboration, and Section 4 provides three recommendations to enhance the United States' ability to engage in QIST research and development (R&D) on the global stage.

II. MOTIVATION FOR INTERNATIONAL COOPERATION IN QIST

For decades, QIST R&D has thrived in a highly international arena and has been interconnected with S&T frontiers in many related fields. Collaboration and cooperation in QIST between the United States and its allies and partners (hereafter, "partners") confers many benefits to the Nation, such as to:

a) Move the science faster.
b) Grow, attract, and engage with international talent.
c) Promote robust access to resources and markets.
d) Guide QIST-related principles, policies, and effective practices in the international community.
e) Strengthen international engagements.

Collectively, these outcomes are essential to U.S. scientific leadership, economic competitiveness, and national security. In the following subsections, each of these benefits will be explored in greater detail.

[1] As described in the National Quantum Initiative Act, QIS means the use of the laws of quantum physics for the storage, transmission, manipulation, computing, or measurement of information. QIST refers to QIS and technologies that leverage it.
[2] https://www.quantum.gov
[3] NQI Act (Pub. L. 115-368), 15 U.S.C. § 8801 et seq. For the NQI Act with amendments made as of October 2022, see https://www.quantum.gov/wp-content/uploads/2022/08/NQIA2018-NDAA2022-CHIPS2022.pdf
[4] https://www.quantum.gov/wp-content/uploads/2023/12/NQI-Annual-Report-FY2024.pdf
[5] https://www.quantum.gov/wp-content/uploads/2020/10/2018_NSTC_National_Strategic_Overview_QIS.pdf
[6] https://www.quantum.gov/wp-content/uploads/2022/02/QIST-Natl-Workforce-Plan.pdf
[7] https://www.quantum.gov/wp-content/uploads/2021/10/2021_NSTC_ESIX_INTL_TALENT_QIS.pdf
[8] https://www.quantum.gov/publications-and-resources/publication-library/

Move the Science Faster. International investment in QIST—in terms of both funding and in developing national strategies—has risen dramatically over the past several years. In this environment, scientific advancement transcends institutions and borders in favor of global knowledge networks. From 2018-2022, roughly half of original, peer-reviewed QIST research published by scientists in the United States involved international collaboration, compared to 40 percent across all scientific publications, indicating the international nature of QIST.[9] Most areas of QIST are nascent, with major scientific challenges that still need to be addressed.[10] International cooperation is crucial to support a thriving culture of discovery and to accelerate the solving of key basic research questions.

Grow, Attract and Engage with International Talent. The rise in international investments in QIST has created competitive opportunities for talented researchers to pursue their work around the globe. As discussed in the *QIST Workforce Development National Strategic Plan* and *The Role of International Talent in QIS* report,[6,7] production of domestic QIST talent is not meeting the demands from U.S. academia, industry, and government. Thus, the United States should leverage existing pathways for international talent to participate in the U.S. workforce and consider new efforts to continue to attract and retain the talent required to achieve U.S. QIST goals. At the same time, the United States should work to ensure that the QIST talent bases of partner nations remain strong and interconnected. In addition, international engagement at the company or researcher level creates familiarity with the industrial and technical developments in partner nations, which can facilitate the growth of scientific and economic interaction.

Ensure Robust Access to Resources and Markets. Key resources for QIST research, development, and commercialization are spread across the world. Resources include scientific and technical expertise, critical components, infrastructure, laboratories with modern equipment, hardware testbeds, and foundries. Strengthening and expanding access to resources will lower barriers to collaborative R&D and commercialization, which will drive the development of critical components and facilitate a sustainable supply chain. Access to global markets is also important to ensure that QIST-relevant products and services can broaden their reach, generate revenue, and benefit all collaborators. Thus, enabling continued access to resources and markets between trusted partners is vital for the health of the global QIST community, while maintaining U.S. global competitiveness and ensuring national security.

Guide QIST-Related Principles, Policies, and Effective Practices in the International Community. International QIST activities should be guided by shared principles, policies, and effective practices that promote the open and fair pursuit of S&T, including respect for intellectual property (IP), data sharing practices, and standard-setting processes, as well as the protection of privacy, civil rights, and civil liberties. International collaboration and cooperation should promote merit-based competition, rigor and integrity in research, and effective research security. Forums like the G7, G20, Organisation for Economic Co-operation and Development (OECD), and others include discussions on emerging technologies and science policy matters relevant to QIST. Bilateral S&T agreements can articulate that cooperation should be built upon shared values, specify rights and obligations relating to IP protection, and set rules for dispute settlement related to such rights.

[9] Statistics from the Incites database, comparing QIST articles from 2018-2022 compared to all articles in the same time period.
[10] https://www.quantum.gov/wp-content/uploads/2020/10/QuantumFrontiers.pdf

Box on Pursuing Quantum Information Together - Roundtable Discussions

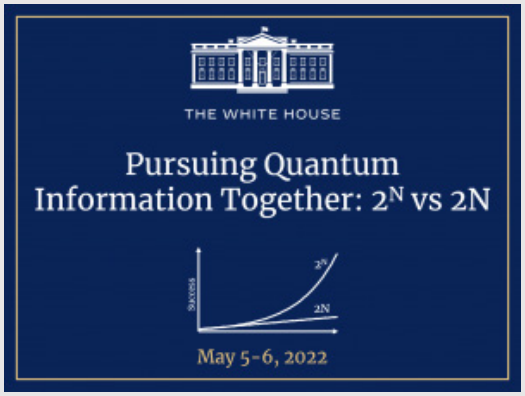

Figure: (Left) Picture of the participants from the inaugural meeting on Pursuing Quantum Information Together. (Right) Poster from the meeting at the White House.

It is U.S. policy to promote and support international cooperation on QIST research and skills development, especially in ways that affirm principles of scientific rigor and research integrity, freedom of inquiry, merit-based competition, openness, and transparency. These ideals are reflected in the bilateral quantum cooperation statements that the United States has signed with Australia, Denmark, Finland, France, Germany, Japan, the Republic of Korea, the Netherlands, Sweden, Switzerland, and the United Kingdom.

In 2022, the National Quantum Coordination Office (NQCO) and the State Department launched an international roundtable on *Pursuing Quantum Information Together: 2^N vs 2N*. This roundtable reinforced the importance of international cooperation in QIST to accelerate discovery, share resources, and jointly address global challenges.[11] The most recent meeting in October 2023 was cohosted by Denmark and the Netherlands. At this meeting, the group discussed a set of draft guiding principles for supporting the global QIST community, as well as ensuring that it is informed by the best available data:

1. Promote scientific collaboration and the exchange of ideas to support quicker scientific discovery in QIST.
2. Incorporate subject-matter expertise in policy discussions and decisions.
3. Share best practices and coordinate outreach in joint efforts to grow the QIST talent base.
4. Promote research security, align and reinforce technology protection measures, and support a fair marketplace to create a vibrant and trusted global QIST industry.
5. Plan for the deployment of quantum-resistant cyber infrastructure, such as quantum-resistant cryptography, to responsibly address the risks of QIST.
6. Increase quantum awareness and readiness in the development and use of quantum-based technologies and applications.
7. Encourage the discovery of QIST use cases for the benefit of society.

Standards play an important role at each stage of technology development: standard terminology helps bridge diverse stakeholder communities; standard measurement and characterization techniques both help mature new technology and provide consumer confidence in commercial

[11] https://www.quantum.gov/readout-international-roundtable-2n/

products; interface standards provide the foundation for a plug-and-play market; and certification and test standards establish a basis for trust. Standards are developed through consensus at appropriate forums and are intrinsically collaborative. However, standards can also be used to create a competitive advantage. Some countries that do not share the values of the United States may try to exert undue influence in an emerging market, like QIST, by attempting to aggressively steer standards creation bodies. To counter this undue influence, the United States should work multilaterally to protect the integrity of the international standardization forums, in alignment with the objectives of the *U.S. Government National Standards Strategy for Critical Emerging Technology*,[12] and help to ensure that resulting standards reflect shared values and are based on the best available data.

The early development stage of QIST also presents an opportunity for the global QIST community to engage with policymakers and the public. This engagement can address unrealistic expectations and counter misunderstandings regarding the potential capabilities, applications, and timelines of QIST. The United States can play a leading role, but international cooperation is needed to ensure that the potential benefits and risks of QIST are well understood and that future policies and decisions related to QIST are based on the best available data, while supporting a vibrant and secure global ecosystem. The Box on Pursuing Quantum Information Together describes multilateral roundtables that discuss these topics.

Strengthen International Engagements. Historically, international collaboration has provided common ground through which nations can deepen relationships. These relationships have in turn provided platforms to establish trust, share and demonstrate mutually affirmed values, and facilitate communication. Therefore, international engagements centered around QIST can serve as a platform for strengthening international cooperation that may have impacts beyond the field. For example, the U.S. Government has signed a number of bilateral quantum cooperation statements with foreign partners. The mechanisms and dialogues created to support these activities within the framework of the QIST statements are immediately applicable across other technology and social arenas.

III. CURRENT PATHWAYS AND OPPORTUNITIES FOR INTERNATIONAL COOPERATION AND COORDINATION IN QIST

Strong, sustainable S&T cooperation is best achieved by enabling scientists and technologists engaging in R&D to interact with each other and drive specific activities. While high-level S&T discussions with international partners are valuable, the United States develops domestic and international cooperation in fundamental QIST research from the bottom up. Researchers, for example, are best suited to identify and form meaningful R&D collaborations, and promising technical programs are more apt to be identified by an expert's merit-based review of research proposals than by high-level discussions. Accordingly, strengthening QIST collaborations with international partners requires creating mechanisms and opportunities for experts to interact; explore shared interests; identify complementary capabilities; and then pursue specific activities together. As the level of interest has grown around the globe, U.S. entities are receiving an influx of new requests for international agreements and engagements. To avoid overwhelming the U.S. QIST community, the United States should prioritize QIST collaborations that support meaningful scientific, technological, and/or economic value. As the number of international activities and interest grows, each agency will remain responsible for finding and realizing international opportunities in accordance with their mission set.

[12] https://www.whitehouse.gov/wp-content/uploads/2023/05/US-Gov-National-Standards-Strategy-2023.pdf

ADVANCING INTERNATIONAL COOPERATION IN QIST

The *National Strategic Overview for QIS* establishes international cooperation as a core pillar of maintaining competitiveness, with QIST activities—including international efforts—informed by each agency's mission space and specific authorities. While authorities vary by agency, many have mechanisms that can support international collaboration, including funding for U.S. portions of joint research activities, support for international students working in U.S.-funded labs, support for visiting international researchers accessing U.S. research infrastructure, and some limited options for directly funding international researchers. For instance, the National Science Foundation (NSF) can support collaborative international projects in QIST that are jointly funded by NSF and partnering organizations. International institutions participate in the Department of Energy's (DOE's) QIST activities through collaborations with DOE National Laboratories or U.S. universities, including as partners in DOE's National QIS Research Centers, and as users of DOE user facilities, which are open to researchers worldwide. The Department of Defense (DOD) can directly fund international R&D through the services' international offices. The National Institute of Standards and Technology (NIST) collaborates with National Metrology Institutes globally to develop and validate measurement capabilities and standards.

This federated approach to U.S. Government-sponsored R&D has served U.S. innovation well. The decentralized structure provides a diversity and flexibility that often results in a great variety of S&T solutions. This distributed funding model, however, can create challenges for U.S. participation in substantial and concerted international collaboration. A one-size fits-all approach to international activities is infeasible due to differences in agency authorities across the U.S. Government. Thus, the U.S. Government should take steps to increase the ability of agencies to realize the positive impact of international engagement in QIST.

Several mechanisms exist to reinforce agency participation in international cooperation and collaboration opportunities related to QIST. This includes the National Science and Technology Council (NSTC) Subcommittee on QIS (SCQIS) and the Subcommittee on the Economic and Security Implications of QIS (ESIX). Additionally, the NSTC Subcommittee on International Science and Technology Coordination (ISTC) focuses on international S&T cooperation more broadly, including QIST.[13] The State Department informs and enables international engagement in close connection with QIST-related interagency groups, while the National Quantum Coordination Office (NQCO) serves as a central point of contact to assist with QIST-related inquiries from foreign partners; however, neither the State Department nor the NQCO has a significant R&D budget to drive international collaborative activities. Additional international cooperation efforts include those undertaken at the Department of Homeland Security, the National Institutes of Health, and the National Aeronautics and Space Administration. This list is not intended to be comprehensive, but rather illustrates some of the range of activities of agencies engaged in international cooperation.

[13] https://www.whitehouse.gov/wp-content/uploads/2024/02/2024-Biennial-Report-to-Congress-on-International-Science-Technology-Cooperation.pdf

IV. RECOMMENDATIONS TO ADVANCE INTERNATIONAL COOPERATION IN QIST

Formalized international engagements should be made in a targeted manner, anchored to national priorities and goals including national security considerations. These engagements should be informed by criteria such as critical or complementary QIST R&D capabilities, supply chain equities, and significant alignment with U.S. agency missions. Engagements through community-led activities, such as technical workshops, talent mobility, and researcher-to-researcher interactions, are particularly valuable as countries establish national efforts and QIST strategies.

U.S. participation in international QIST-relevant discussions strengthens its networks and partnerships with international stakeholders and helps to identify opportunities for improved collaboration. With much of QIST being pre-competitive, early engagement and dialogue in multinational forums can foster an environment conducive to innovation and investments across borders. As new and unforeseen applications become apparent, multilateral engagement provides an opportunity to proactively share information on emergent possibilities, accelerate fundamental discovery and early technology adoption, and take collective action to mitigate negative impacts while promoting and cultivating positive outcomes.

Agencies should continue leveraging existing programs, such as the State Department's Embassy Science Fellows, U.S. Science Envoys, and Regional Technology Officers programs, and the DOD's Engineer and Scientist Exchange Program to support engagements, as well as strengthen and build a cadre of U.S. experts with international expertise and networks. Additionally, agencies involved in QIST should consider coordinating and strengthening engagement across various forums where QIST-relevant standards, guiding principles, and policies are discussed.

As quantum-enabled technology advances and attracts more public attention, governments around the world may move to preemptively inhibit cooperation—even for early-stage research—to retain a perceived strategic advantage. Such actions could significantly stunt the growth of the field, stress resources, and undermine fundamental research. The United States should work with its international partners to encourage a unified voice based on economic data, sound scientific reasoning, and shared principles, such as those discussed in the Box on Pursuing Quantum Information Together.

Motivated by the importance of international cooperation and by the current challenges articulated in earlier sections, this report makes three recommendations for the United States to advance international cooperation in QIST toward an overarching goal:

Overarching Goal: Enable international cooperation that imparts mutual benefits and prioritizes shared values, scientific purpose, and economic promise.

Recommendations:

1. The U.S. Government should create dedicated and long-term mechanisms to fund international QIST collaboration and cooperation.
2. Agencies should enhance interagency coordination of international cooperation practices to reinforce an integrated U.S. Government-wide portfolio for international QIST engagement.
3. The U.S. Government should establish and track metrics for global competitiveness across QIST and its enabling technologies.

Recommendation 1: The U.S. Government should create dedicated and long-term mechanisms to fund international QIST collaboration and cooperation

Challenge: The United States has a federated funding model with individual agencies having a variety of programmatic mechanisms. This model has been successful for pioneering innovation but can make it more complex for the U.S. Government to participate in large-scale, multinational cooperative partnerships, which may inhibit the Nation's ability to drive and benefit from innovation in QIST. Other countries are actively funding mechanisms that support transborder R&D. For example, over 20 European Union (EU) member states and associated countries participate in the EU's Horizon Europe program. Japan and the United Kingdom, in addition to the People's Republic of China, are a few examples of countries that have dedicated funds for driving international collaboration. As another example, a Eureka call for funding international collaboration on applied quantum technologies drew support from 16 countries.[14] The United States, however, was not well situated to participate due to lack of established interagency mechanisms. By prioritizing dedicated international cooperation funding for QIST, the United States can demonstrate leadership, nurture the talent pipeline and supply chain, and accelerate the deployment of quantum technologies.

Discussion of Recommendation: The U.S. Government should establish a new, dedicated, and centralized mechanism for supporting a broad range of international QIST activities. These activities include joint R&D projects, workforce mobility, and the participation of U.S. QIST experts in various international forums where QIST policies, standards, export controls, and security practices are developed. New authorizations and appropriations would significantly enhance the United States' ability to collaborate internationally. The State Department is well-positioned to steward this effort, coordinated through the SCQIS and ESIX. In parallel, agencies could explore using existing authorities to support international cooperation individually, or through the pooling of funds across agencies, if appropriate to meet the agencies' needs, to be executed in close coordination with those contributing.

This centralized mechanism supporting international QIST cooperation would complement ongoing agency activities and strengthen the United States' ability to engage on collaborative projects. It should enhance and complement, rather than supplant, ongoing domestic and international R&D efforts. By partnering with the international community, the United States and its partners can leverage the unique strengths of each other's R&D pipeline. Jointly funded efforts could also be used to broaden the implementation of effective practices for technology protection. Building nimble, sustained, and dedicated resources to support U.S. participation in cooperative international efforts will provide programmatic flexibility to engage with the various technical focuses of international partners.

This recommendation complements the 2022 and 2024 NSTC ISTC Biennial Reports to Congress that recommended the creation of a dedicated and flexible mechanism within the State Department to support international S&T cooperation.[15] Those reports noted that foreign governments are increasingly supportive of multinational research consortia (e.g., Horizon Europe) and that, in contrast, the United States lacks similar initiatives. The NQI Advisory Committee made a similar recommendation for a dedicated QIST international cooperation fund.[16] This common theme from U.S. Government and advisory bodies points to a need for new ways to support U.S. participation in international activities.

[14] https://eurekanetwork.org/opencalls/network-projects-quantum-call-2024/

[15] https://www.whitehouse.gov/wp-content/uploads/2022/09/09-2022-Biennial-Report-to-Congress-on-International-Science-Technology-Cooperation.pdf and https://www.whitehouse.gov/wp-content/uploads/2024/02/2024-Biennial-Report-to-Congress-on-International-Science-Technology-Cooperation.pdf

[16] https://www.quantum.gov/wp-content/uploads/2023/06/NQIAC-Report-Renewing-the-National-Quantum-Initiative.pdf

Recommendation 2: Agencies should enhance interagency coordination of international cooperation practices to reinforce an integrated U.S. Government-wide portfolio for international QIST engagement

Challenge: The international QIST community is expanding and generating many new opportunities for collaboration. Often a single country will approach multiple U.S. agencies individually to propose formal and informal partnerships. Agency staff may be unaware of ongoing partnerships that could be leveraged for cooperation. Instruments for international cooperation, such as memoranda of understanding (MOUs) or agreement (MOAs), often involve protracted timelines and significant resources to develop and implement. These inefficiencies delay progress and can result in duplicative efforts, further straining limited resources. Enhanced coordination is needed to share effective practices and limit redundancies.

Discussion of Recommendation: New or revised processes and tools to explore and implement international engagements are vital to strengthening the U.S. QIST enterprise. These processes and tools should reduce barriers, facilitate the sharing of effective practices, enhance technology protection, and attract and leverage joint investments.

As a first measure, agencies should leverage the SCQIS Interagency Working Group on International Cooperation (International IWG) as a dedicated space for coordination of international opportunities. As an informational hub, the International IWG enables the agencies to share newly identified trends and engagement opportunities in the global QIST community more effectively. It is also a venue to capture agency-specific perspectives and insights, as well as share and review information from U.S. personnel working internationally (such as Embassy Science Fellows, U.S. agency program offices abroad, and Regional Technology and Trade Offices). Finally, the International IWG can be used to better leverage metrics for quantifying scientific progress or other landscape-surveying activities that would inform existing engagements and identify new ones.

Developing and maintaining an awareness of global developments in QIST will require bolstering formal and informal mechanisms. Coordinating, cooperating, and engaging with our trusted partners can alleviate stress on supply chains and the workforce pipeline, while helping establish economies of scale. Agencies that fund and lead QIST R&D should identify trusted partners in the international community that can accelerate ongoing work. Potential end users and technology integrators, such as agencies that leverage the classical counterparts to quantum-enabled technologies, should jointly investigate use cases with the international community that will benefit society.

Jointly funded and other formal cooperative projects often require written arrangements between the foreign and U.S. counterparts. These arrangements, however, can often take many months, if not years, to establish, while science moves more quickly. In addition, the timelines to formalize these arrangements can exceed the length of the programs they are intended to advance. Consequently, the payoff may not be realized to the individuals that initiated the cooperation. Agencies should incentivize staff to allocate time and resources to develop cooperative relationships with partners, when appropriate, that will have long-lived impacts. In addition, agencies should reduce bureaucratic hurdles, when appropriate, to streamline the development of new formal international arrangements, while leveraging existing bilateral and multilateral agreements and arrangements. Finally, agencies should ensure that new agreements or written arrangements are appropriately reviewed and socialized with interagency partners, and incorporate research security and scientific integrity practices.

Recommendation 3: The U.S. Government should establish and track metrics for global competitiveness across QIST and its enabling technologies

Challenge: Tracking international competitiveness and progress toward usable quantum technologies is a challenge for the field. The immense diversity in technology, maturity level, and end-use makes it difficult to communicate progress and priorities across different countries, regions, and sectors. Standard quantifiable metrics, such as bibliometric and patent data, are informative but do not neatly capture meaningful progress toward a technology platform of value. Additionally, a metric like funding indicates priority but not necessarily competitiveness. Mismatches in terminology and definitions of technology readiness levels (TRLs) complicate comparisons and obscure opportunities for joint ventures. Establishing common terms, metrics, and benchmarks will help track international progress in the field, provide a shared understanding of the international landscape, and provide a language to assess the progression of quantum technologies toward utility.

Discussion of Recommendation: A framework for the U.S. Government to track substantial technical milestones will require dedicated resources, time, and scientific expertise from across the agencies, along with input from the SCQIS and ESIX. Better metrics should be developed that account for the QIST workforce and supply chain, used in conjunction with the above mentioned bibliometrics, patent data, and funding data. In addition, through the International IWG and Workforce IWG, the U.S. Government should track the change and flow of the workforce and funding as a complement to total numbers. For example, effective measures should indicate which countries are producing a QIST workforce and how this workforce migrates across borders, as these metrics may ultimately reflect the pull of the most promising opportunities and impact of funding. Measurements of supply chain contributors and consumers at the system and component levels complement measures of workforce and overall investment by presenting different facets of technical capability. For example, the quantum technologies a country imports indicates their ability to use and integrate them, while the export or commercialization of technologies signifies skilled areas of reliable fabrication and device engineering.

The interdisciplinary nature of the quantum workforce poses a significant challenge to effectively measuring the amount of quantum talent. Quantum information scientists and technologists come from a variety of degree programs including computer science, engineering, mathematics, and physics, and there is no universal indicator that any given worker is a part of the QIST workforce. Similarly, the supply chain is vast, and representative data of the contributors and consumers of the supply chain may be difficult to obtain. Therefore, the United States should prioritize dedicated studies to develop, track, and analyze these metrics.

As quantum technologies reach a maturity appropriate for standards-making, the United States should be a leader. As an initial step, the United States should develop a common set of definitions[17] and indicative benchmarks across QIST with international partners that are technology agnostic. Not only would such an effort track progress, but it would also be an aid to identify when compelling applications and technologies warrant increased attention.

[17] See for example https://www.nist.gov/publications/single-photon-sources-and-detectors-dictionary

V. CONCLUSION

International cooperation will remain a vital component of the U.S. strategy for QIST. The international cooperation pillar of the *National Strategic Overview for QIS* emphasized efforts including regular reviews of international collaboration activities and partnerships, identification and prioritization of strategic bilateral partnerships, and encouragement of merit-based and transparent fundamental research and innovation systems. This report expands on the *National Strategic Overview*, supporting and building out the policy pillar of international cooperation. In conclusion, this report recommends that the United States should:

1. establish new resourcing and dedicated long-term mechanisms to nurture international partnerships in QIST,
2. enhance and strengthen interagency coordination on a portfolio of international engagements, and
3. establish and track metrics for measuring global competitiveness in QIST.

These recommendations complement those in the report on *The Role of International Talent in QIS*, which encouraged agencies to continue and enhance their support of research exchanges and work with partners on consistent technology protection plans. Taken together, these recommendations will support U.S. leadership in QIST and the continued development of a global QIST enterprise that is science driven, vibrant, and secure.