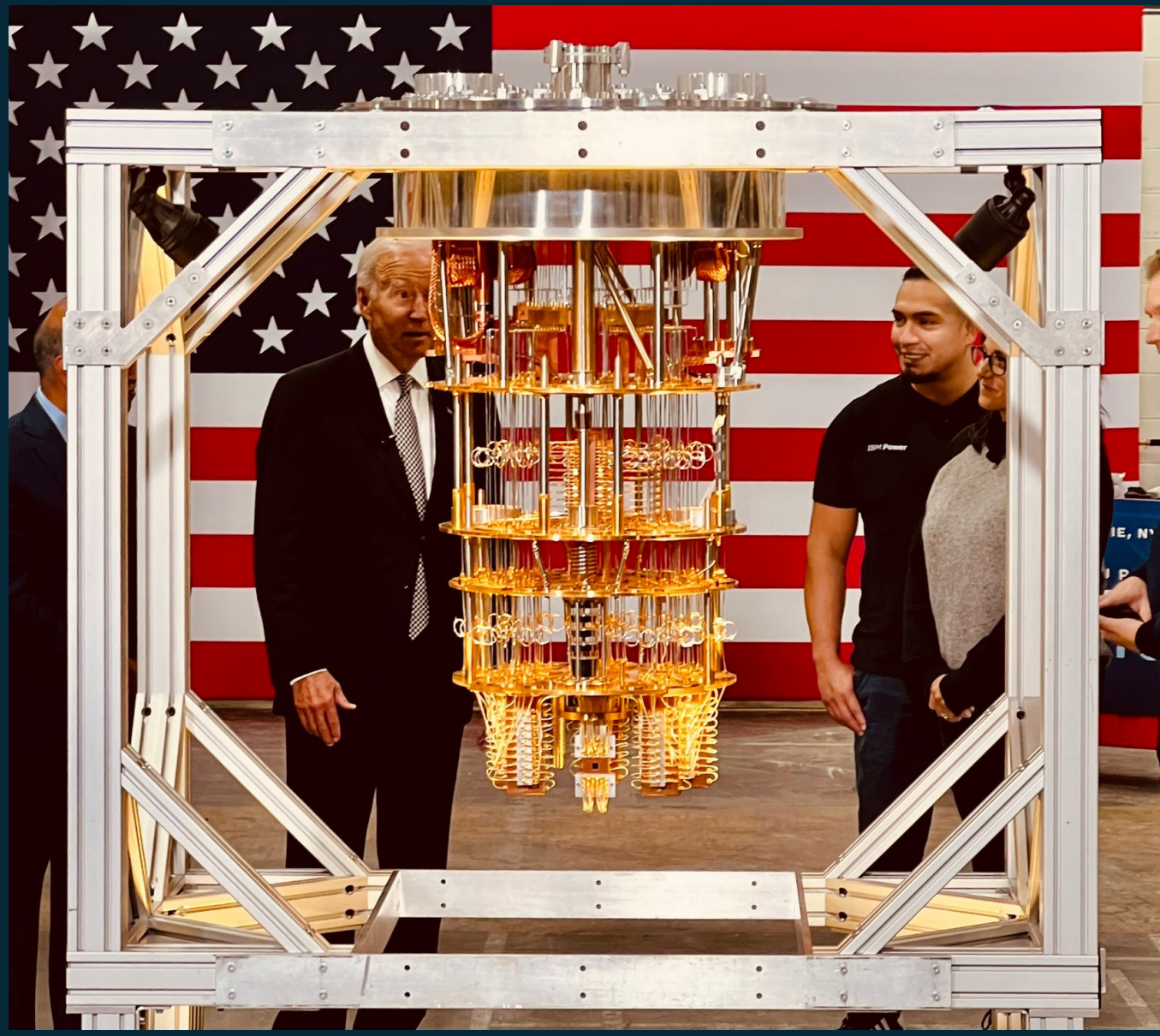
Quantum Information Science

Charles Tahan

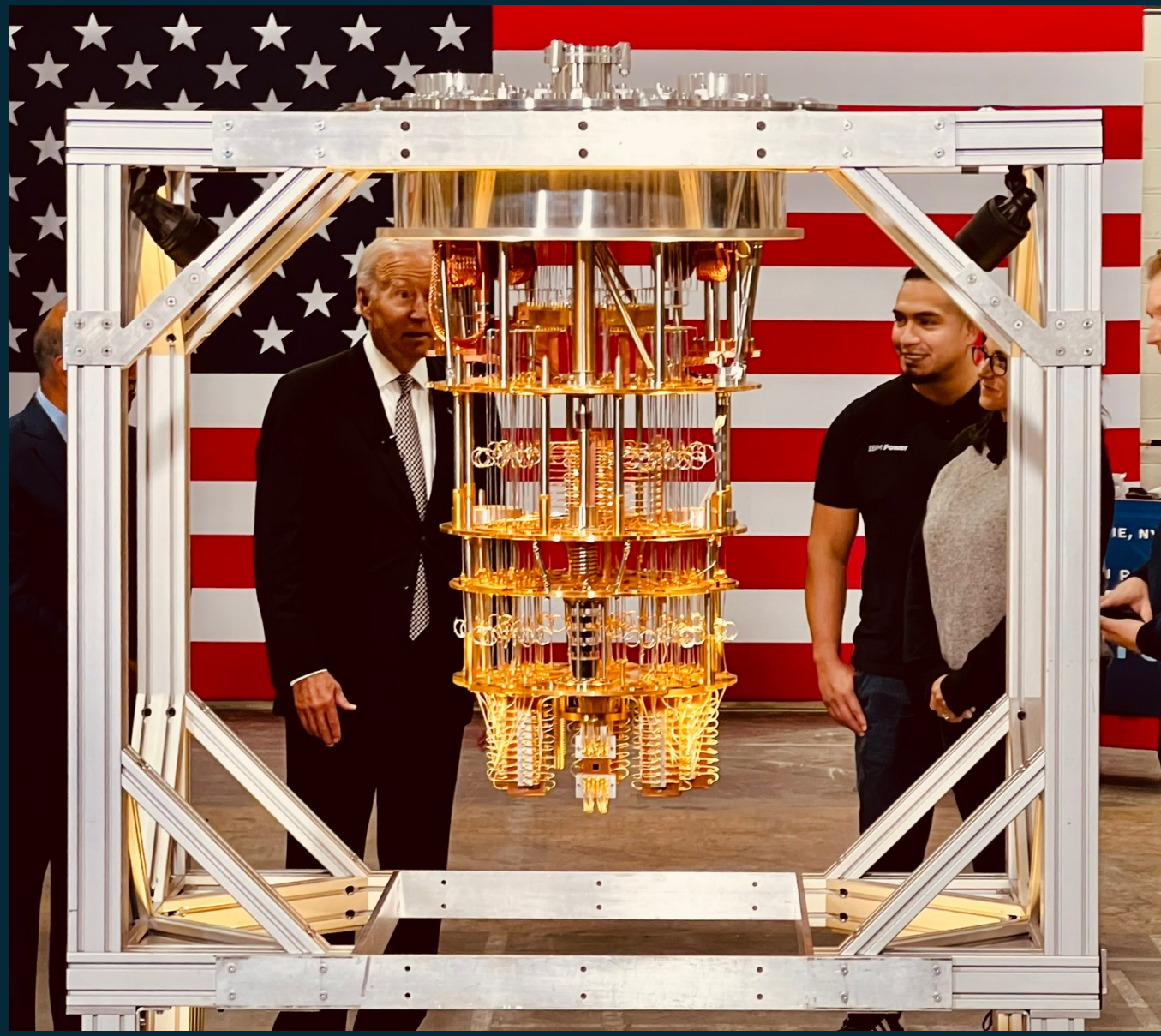
Assistant Director for QIS and Director of the National Quantum Coordination Office, Office of Science and Technology Policy

Chief Scientist & Chief of QIS, Laboratory for Physical Sciences

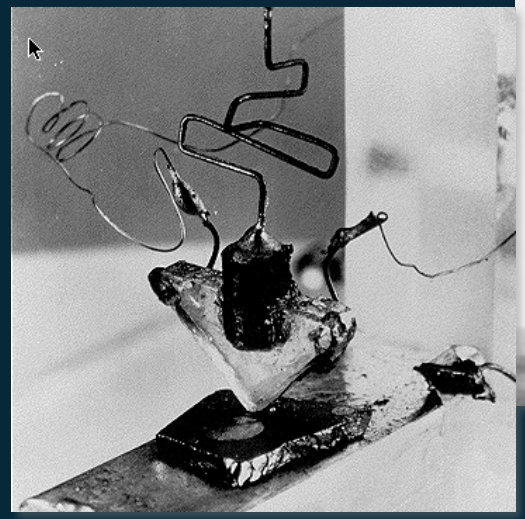
- Best picture of the year?

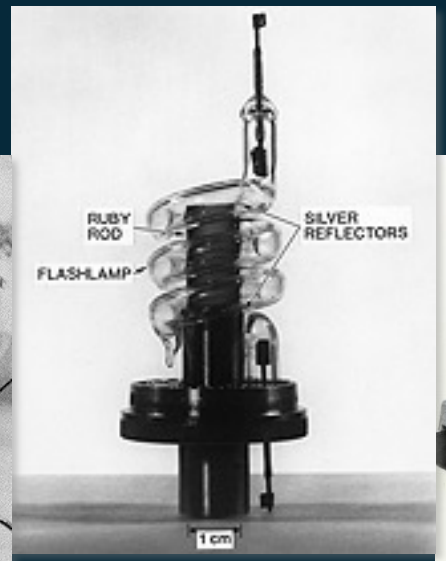


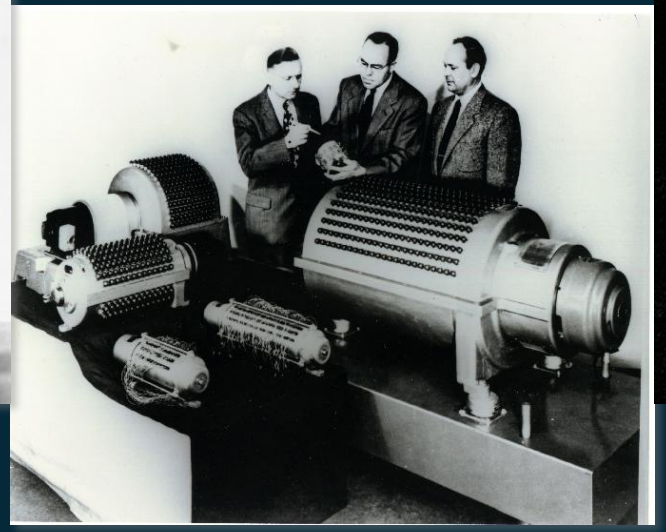
- Second best.



Quantum mechanics enabled modern computing and communication







The TRANSISTOR, LASER, MAGNETIC STORAGE, and MRI could not have been developed without an understanding of quantum mechanics, primarily the "benign" parts of QM, such as energy levels.

Physical devices allow us to manipulate information

- Quantum mechanics are the rules that describe how really small things behave.
- Discovered over 100 years ago, these curious facts about matter enabled humans to design the transistor, ultra-precise clocks, and brain imagers.
- With these physical devices in hand, we built abstractions. The most amazing of which are computers and the programming languages that control them.
- But while physical devices allow us to manipulate information, information is also physical. The 0's and 1's that humans came up with – what came to be called computer science or information theory – works great, except, that the universe works by the laws of quantum mechanics.

But quantum physics problems are really hard to solve on computers. So, what if you could build a computer based on the laws of the Universe – a "quantum computer"…?

1. No efficient computer simulations of quantum theory

2. Systems evolving according to quantum theory efficiently compute properties of the quantum system – Nature is quantum

"How can we simulate quantum mechanics?... Can we do it with a new kind of computer…a **quantum computer**? It's not a Turing machine but a machine of a different kind" (1981)

***Naively*, adding a single particle (or orbital) doubles the size of the matrix you need to diagonalize.**

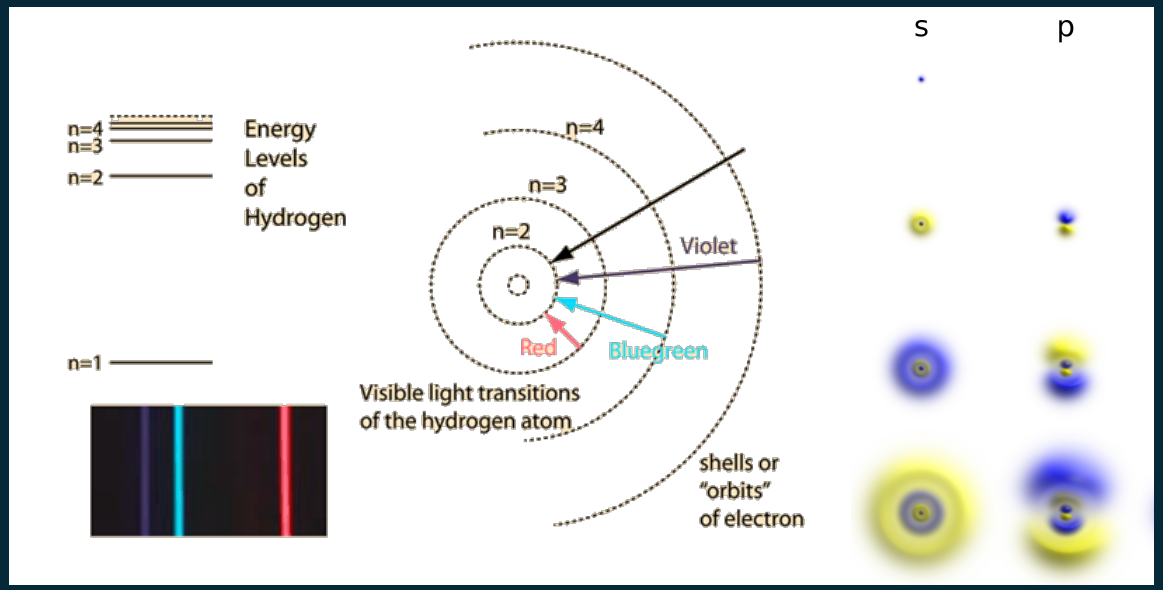
Quantum to *Quantum Information*

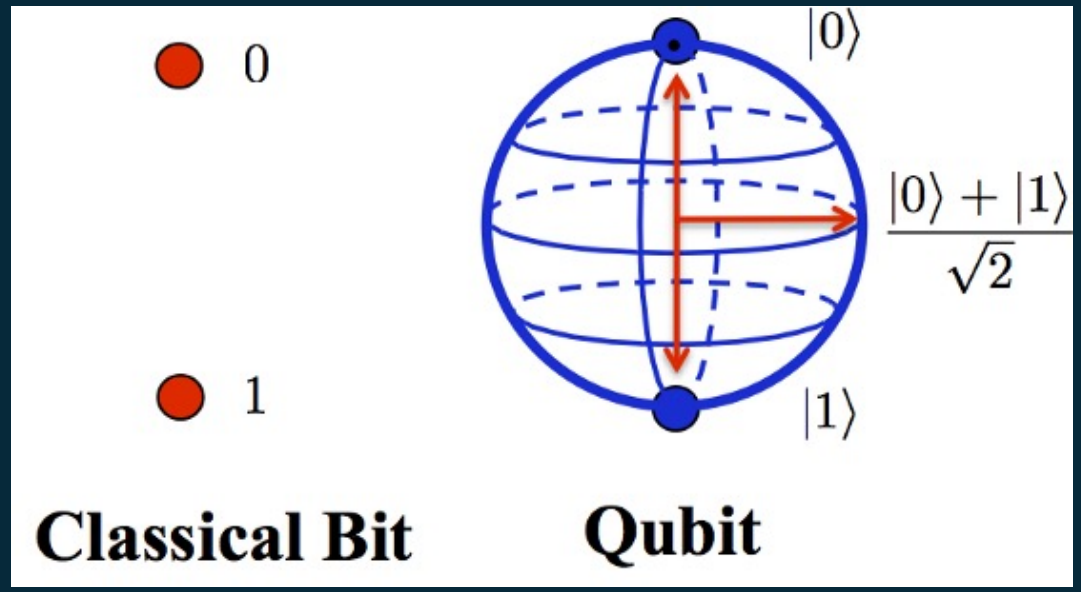
- Quantum 1.0 – particles
  - *Quanta*: atoms, photons, electrons
  - Atoms have discrete energy levels and electron wave functions

  ➔ Electronics, photonics, etc.

- Quantum 2.0 - qubits
  - Quantum superposition/entanglement
  - Quantum measurement: collapse

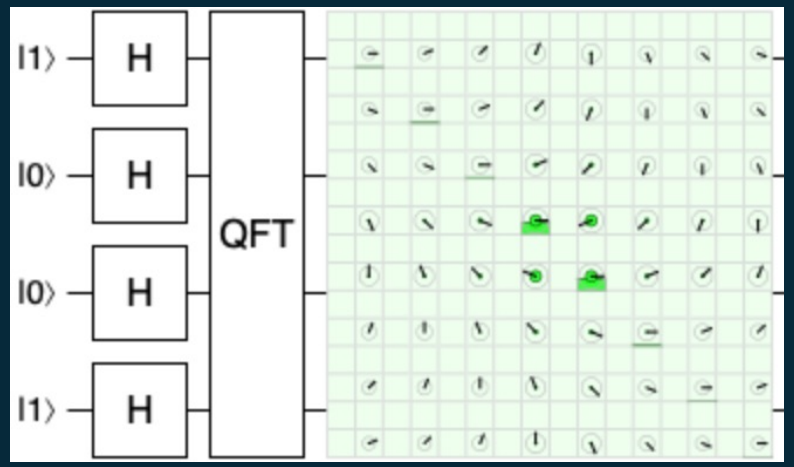
  ➔ Quantum sensors, networks, computers



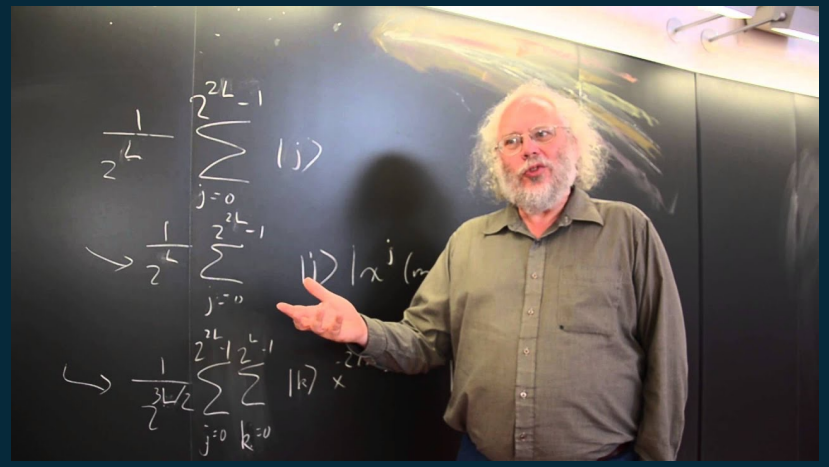


Quantum Information Science is a foundational shift in Information Technology

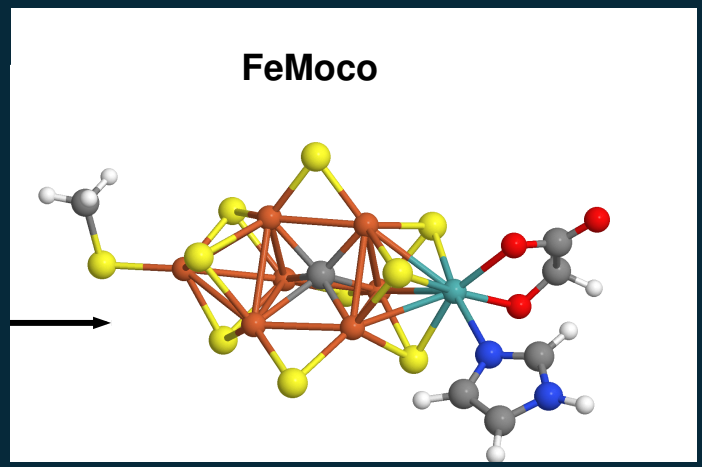
- Consider large-scale quantum computers
- QCs offer dramatic speed up for *a few unique but important* problems



Exploring quantum mechanics
[we can't simulate ~50 (perfect) qubits]



Cryptanalysis
[10+million *physical* qubits breaks modern public key crypto]



Utility?
[?100-1000 *logical* qubits does something economically useful in chemistry/materials science]

National Quantum Initiative

Charles Tahan
Assistant Director for Quantum Information Science
Director, National Quantum Coordination Office
Office of Science and Technology Policy

whitehouse.gov/ostp
www.quantum.gov
@WHOSTP

"As new technologies continue to evolve, we'll work together with our democratic partners to ensure that new advances in areas from biotechnology, to quantum computing, 5G, artificial intelligence, and more are used to lift people up, to solve problems, and advance human freedom." – President Biden

Background photo by L. Whitman

QIST is a National Priority

- ***Getting the science right*** by understanding the applications and timelines by which quantum information science and technology will benefit our society, and roadblocks we must overcome to get there;

- ***Enhancing American competitiveness*** by accelerating technology development toward useful economic and mission applications while also protecting our national security; and

- ***Enabling our people*** by building the necessary talent pipeline and ensuring that this field creates new opportunities for all Americans.

Oct 5, 2021: White House Summit on Quantum Industry and Society

Presidential Actions

BRIEFING ROOM

Executive Order on Enhancing the National Quantum Initiative Advisory Committee

MAY 04, 2022 • PRESIDENTIAL ACTIONS

"Quantum information science (QIS) can enable transformative advances in knowledge and technology for industry, academia, and government. Accordingly, the National Quantum Initiative (NQI), which aims to ensure the continued leadership of the United States in QIS and its technology applications, is a substantial and sustained national priority."

"The NQI Program encompasses contributions from across the Federal Government, … with membership on SCQIS or ESIX"

BRIEFING ROOM

National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems

MAY 04, 2022 • STATEMENTS AND RELEASES

Policy: Balance the competing opportunities and risks of quantum computers by (1) maintaining U.S. leadership in QIS; and (2) mitigating the threat of CRQCs through a timely and equitable transition to PQC.

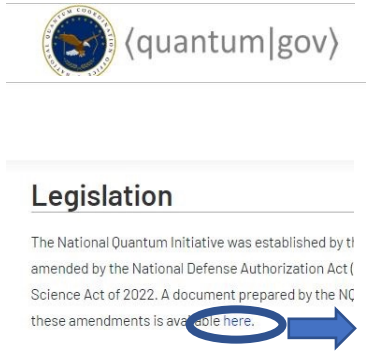
Promotion: The United States must pursue a whole-of-government and whole-of-society strategy to harness the economic and scientific benefits of QIS.

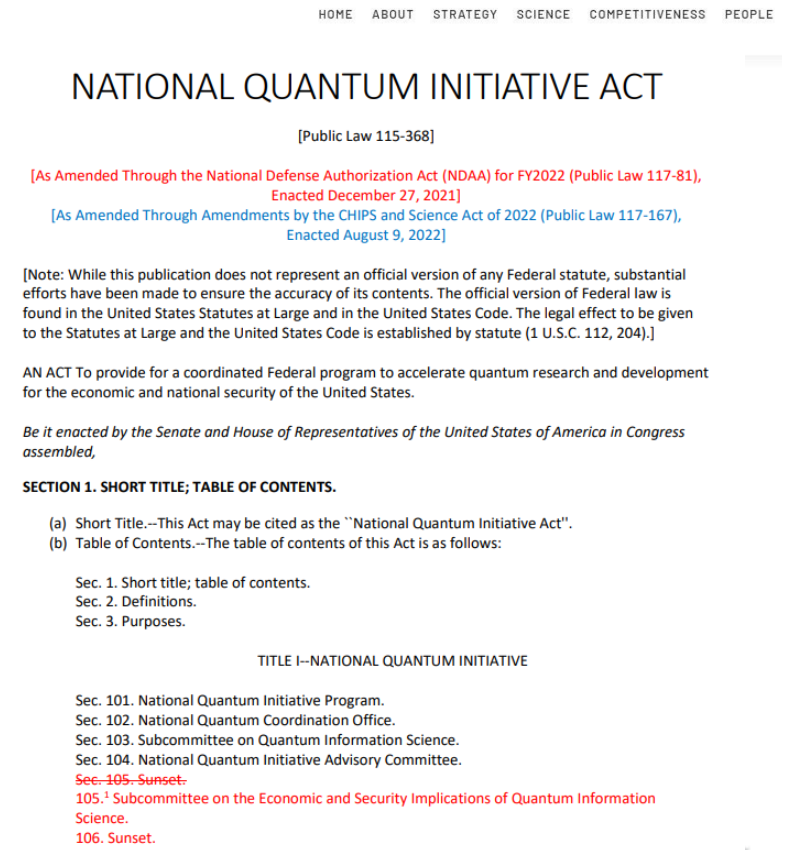
Mitigating Risks: The United States must prioritize the timely and equitable transition of cryptographic systems to QRC.

Protecting US Tech: The U.S. Gov must work to safeguard relevant quantum R&D and intellectual property (IP) and to protect relevant enabling technologies and materials.

Congressional Actions

- NDAA FY22
  - Amended the NQI to formally establish ESIX Subcommittee
    - "review and assess any economic or security implications of such investments; assess the export of technology associated with quantum information science and recommend…"
- CHIPS (approp) and Science Act (auth)
  - Amended the NQI Act
    - QN-IWG to update QN Strategy
    - DOE Quantum Network Infrastructure R&D Program
    - DOE QUEST Program
    - Incorporating QISE into STEM Curriculum
    - NIST development and standardization of quantum and post-quantum cryptography
  - NSF to carry out program on Next Generation Quantum Leaders, leveraging the Q-12 Partnership.





https://www.quantum.gov/wp-content/uploads/2022/08/NQIA2018-NDAA2022-CHIPS2022.pdf

National Quantum Initiative (NQI) Act Oversight/Coordination

NQI COORDINATING BODIES

NSTC Subcommittee on Quantum Information Science (SCQIS)*

NSTC Subcommittee on Economic and Security Implications of Quantum Science (ESIX)**

National Quantum Coordination Office (NQCO)*

NQI Advisory Committee*

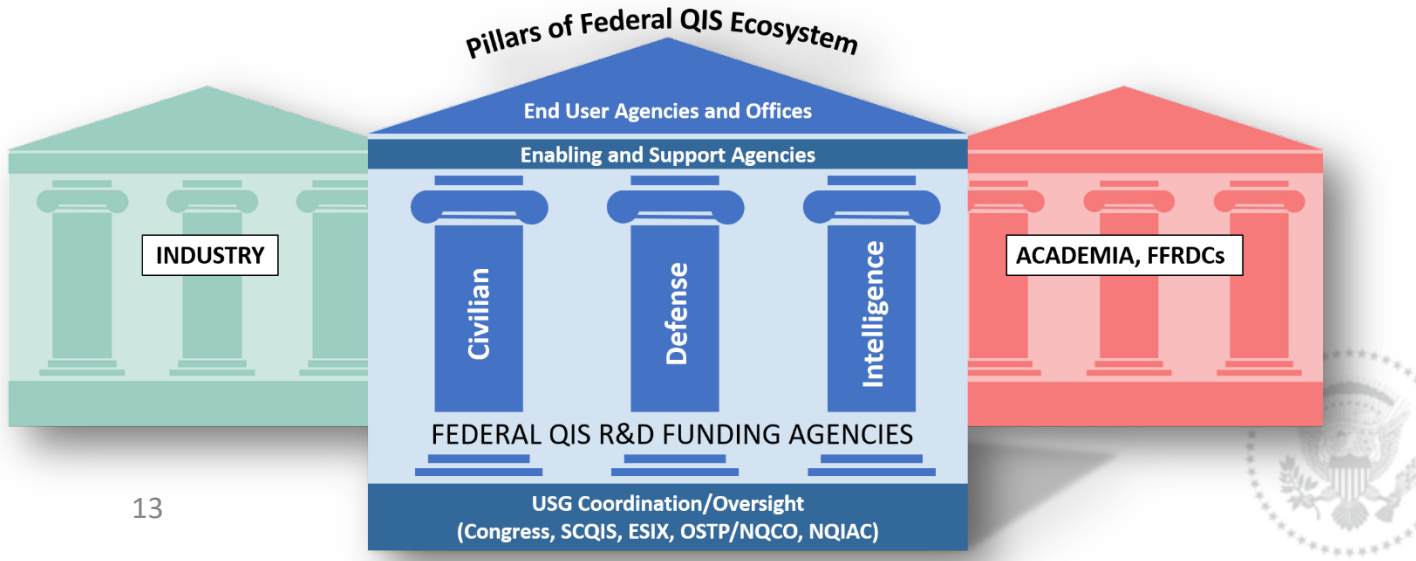
Quantum Economic Development-Consortium (non-gov)

Co-Chairs from:

Co-Chairs from:

Participating Agencies

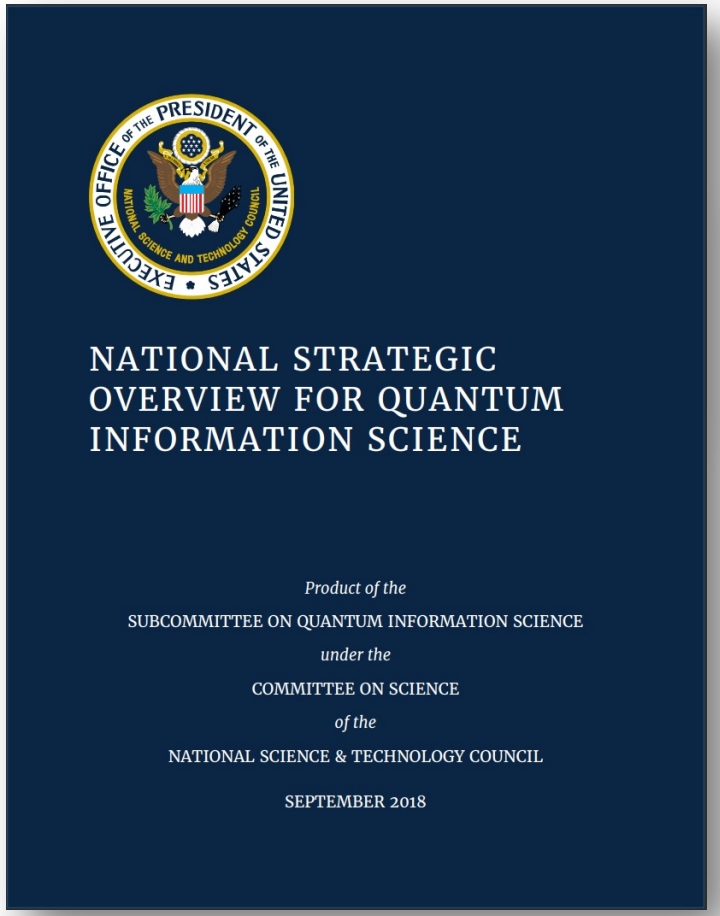
National Institutes of Health

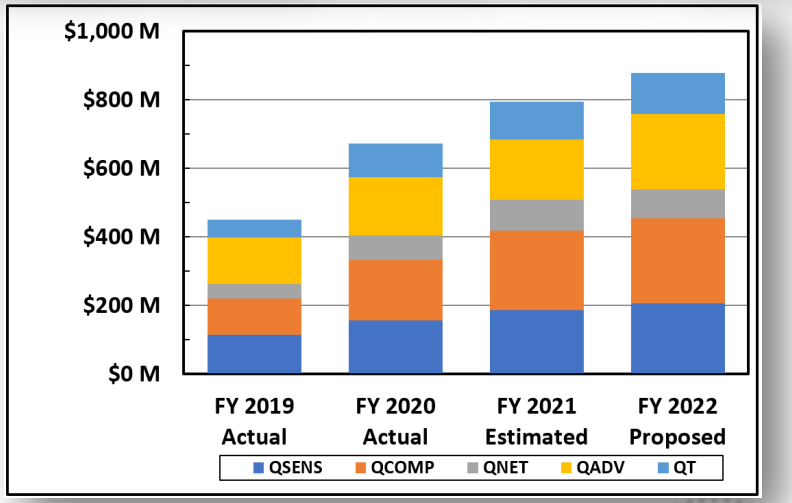


* from National Quantum Initiative Act (PL 115-368) 2018
** from National Defense Authorization Act for FY'22 (PL 117-81)

National Strategy for QIST Continues to Evolve and Expand

1. Take a **science-first** approach
2. Provide the key **infrastructure**
3. Build a quantum-capable and diverse **workforce**
4. Nurture the nascent quantum **industry**
5. Balance **economic** and **national security**
6. Continue to develop **international collaboration** and cooperation

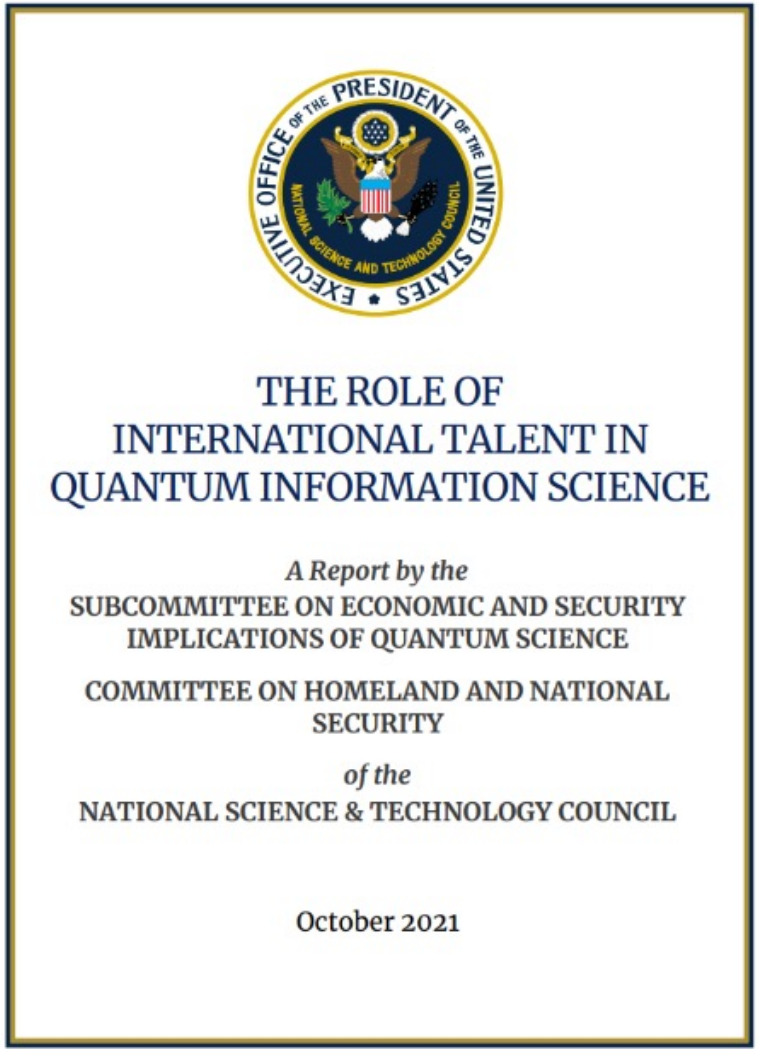


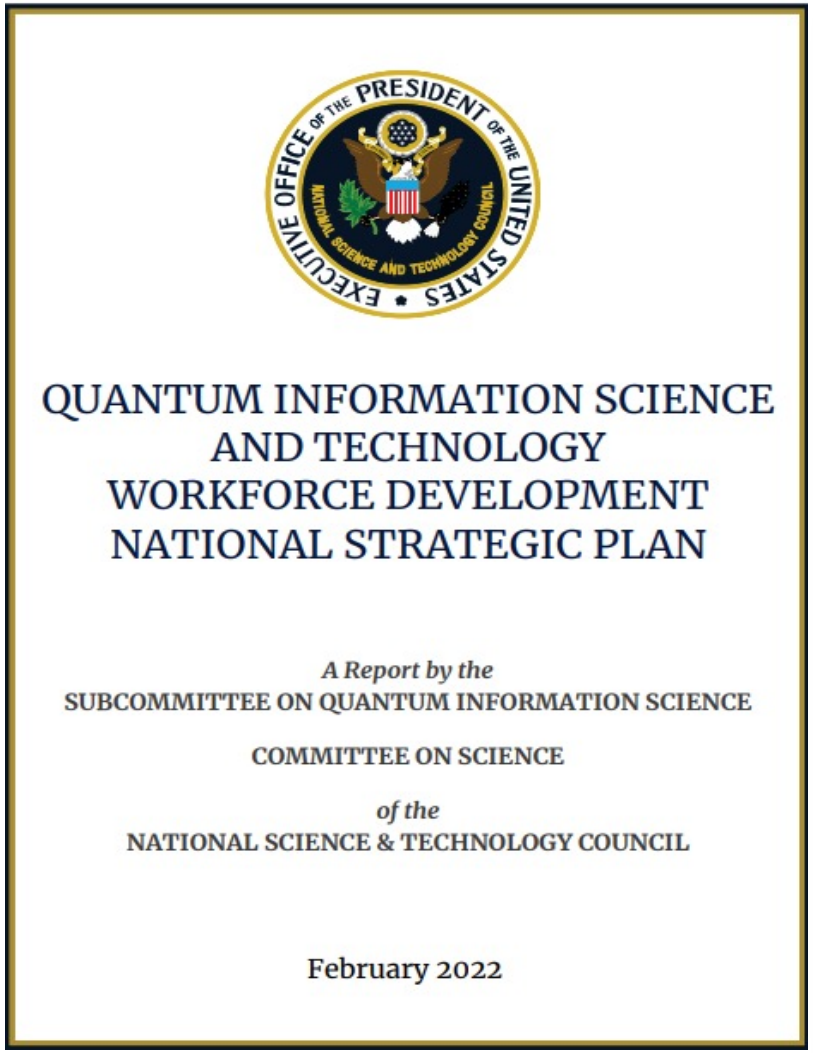


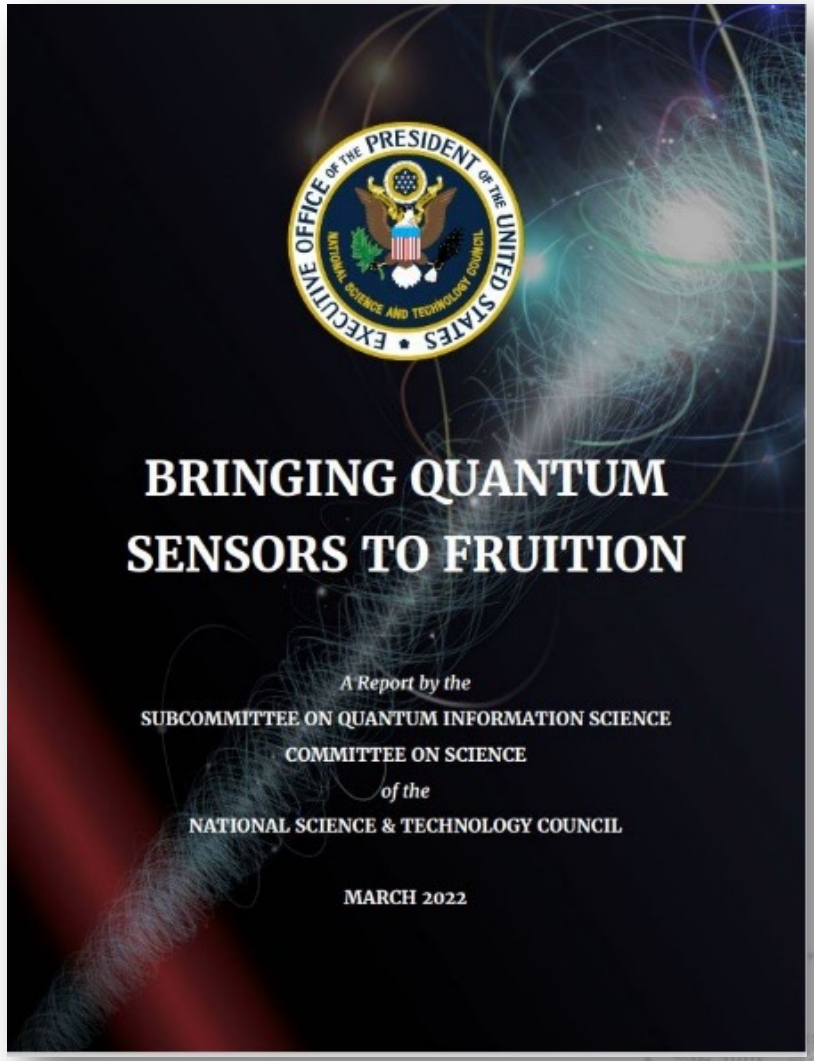
FY21 NQI Annual Report

Find all our strategy documents on quantum.gov

Augmenting the National Strategy





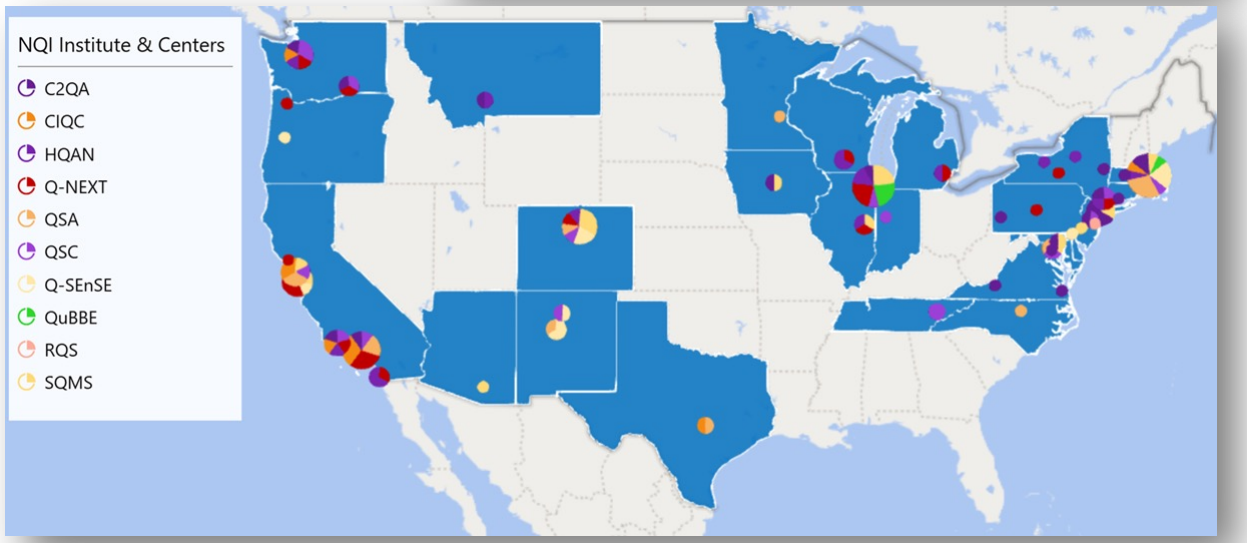


Getting the Science Right

by understanding the applications and timelines by which QIST will benefit our society, and roadblocks we must overcome to get there.

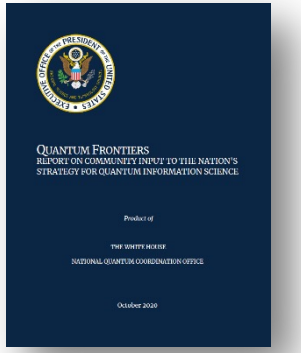
Infrastructure

- 5 DOE National QIS Research Centers
- 5 NSF Quantum Leap Challenge Institutes (+2 FY21)
- 3 DOD/IC QIS Centers (+1 FY21)



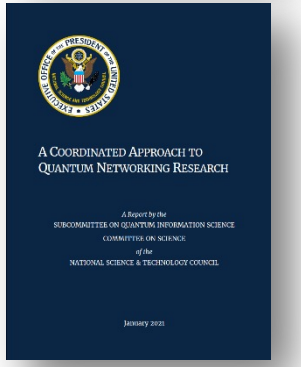
Quantum Frontiers

1. QIST to Benefit Society
2. Building Quantum Engineering
3. Materials Science for QIST
4. Quantum Mechanics using Quantum Simulations
5. QIST for Precision Measurement
6. Quantum Entanglement for New Applications
7. Quantum Errors
8. The Universe through Quantum Information



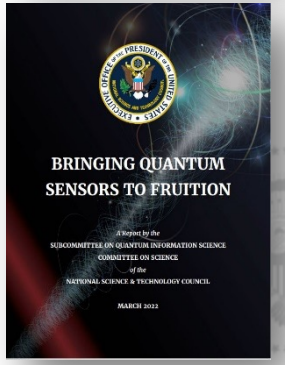
Quantum Networking

TR 1: Continue Research on Use Cases
TR 2: Prioritize Cross-Beneficial Core Components
TR 3: Improve Classical Capabilities
TR 4: Leverage "Right-Sized" Quantum Testbeds
PR 1: Increase Interagency Coordination
PR 2: Establish Timetables for R&D Infrastructure
PR 3: Facilitate International Cooperation



Quantum Sensing

1. QIST R&D leaders should partner with end-users to raise the TRL of new quantum sensors
2. Agencies using sensors should jointly test quantum prototypes with QIST R&D leaders
3. Develop broadly applicable components and subsystems
4. Streamline tech transfer and acquisition practices



New Programs and Solicitations Listed on Quantum.gov

QUANTUM COMPUTING / R&D FUNDING OPPORTUNITIES

IARPA Launching New Program on Entangled Logical Qubits

(July 22, 2022) The Intelligence Advanced Research Projects Activity (IARPA) is launching a new program on Entangled Logical Qubits (ELQ). It is a four-year program scheduled to start in the ...

R&D FUNDING OPPORTUNITIES / WORKFORCE

AFOSR Funding Opportunities in STEM Education, Quantum Welcomed

(March 21, 2022) The Air Force Office of Scientific Research (AFOSR) has two funding opportunities involving STEM education, which could include quantum information science: STEM FOA: This announcement explicitly encourages ...

INTERNATIONAL / NSF / R&D FUNDING OPPORTUNITIES

NSF Funding for International Collaboration in Quantum

(August 18, 2022) The National Science Foundation (NSF) released a Dear Colleague Letter on July 21, 2022 on International Collaboration Supplements in Quantum Information Science and Engineering Research. With this ...

NSF / QUANTUM COMPUTING / R&D FUNDING OPPORTUNITIES

NSF Funds Access to Cloud-based Quantum Computing Platforms

(June 3, 2022) The National Science Foundation, in conjunction with Amazon Web Services (AWS), IBM, and Microsoft, is promoting the availability of cloud-based access to quantum-computing platforms to advance research ...

R&D FUNDING OPPORTUNITIES / WORKFORCE

LPS Supports Young Investigator Program in QIS

(March 17, 2022) The Laboratory for Physical Sciences (LPS), which hosts a National Quantum Information Science Research Center called the LPS Qubit Collaboratory (LQC), is partnering with the Air Force ...

ARL and LPS release BAA on Quantum Computing in the Solid State

(January, 18 2022) A new Broad Agency Announcement (BAA) for the QC-S5 program, BAA # W911NF-22-S-0006 has been released. The U.S. Army Research Office (ARO), in collaboration with the Laboratory ...

QUANTUM SENSING / R&D FUNDING OPPORTUNITIES

DOE BER Releases FOA for Quantum-Enabled Imaging and Sensing for Bioenergy

The DOE SC program in Biological and Environmental Research (BER), through its Bioimaging Research effort, announced its interest in receiving applications to advance fundamental research or use-inspired technologies of new ...

INFRASTRUCTURE / R&D FUNDING OPPORTUNITIES / WORKFORCE

ExpandQISE Solicitation: Invitation to a Connections-Building Workshop

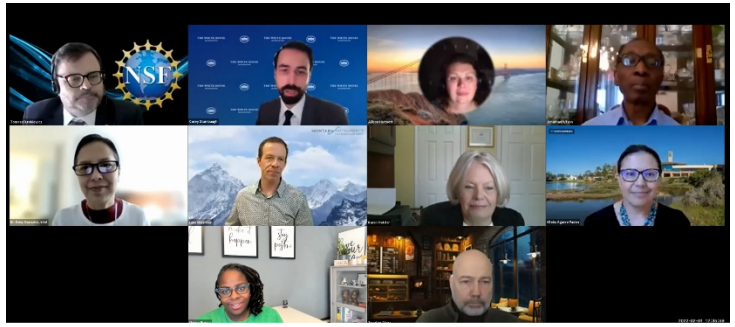
(Feb. 27, 2022) ExpandQISE Solicitation: Invitation to a connections-building workshop. The recently issued program solicitation NSF 22-561 "Expanding Capacity in Quantum Information Science and Engineering (ExpandQISE)" aims to increase research ...

NASA's Space Communications and Navigation (SCaN) program office seeks to enhance faculty professional knowledge and leadership experience by offering two 10-week summer fellowship opportunities for educators who are interested in ...

Stakeholder Engagement

WH Summit on Quantum Industry and Society

WH Meeting on Quantum Workforce: Q-12 Actions for Community Growth



Factsheets and more on quantum.gov

⟨quantum|gov⟩

FEDERAL WORKFORCE ACTIVITIES IN QUANTUM INFORMATION SCIENCE

OVERVIEW

The 2018 National Strategic Overview for Quantum Information Science (QIS) identifies creating a quantum-smart workforce for tomorrow as a key policy area. The strategy for creating this workforce is detailed in the 2022 report, Quantum Information Science and Technology (QIST) Workforce Development National Strategic Plan, and it includes four critical actions:

1. Develop and maintain an understanding of the **workforce needs** in the QIST ecosystem, with both short-term and long-term perspectives.
2. Introduce **broader audiences** to QIST through public outreach and educational materials.
3. Address QIST-specific **gaps** in professional education and training opportunities.
4. Make **careers** in QIST and related fields more accessible and equitable.

One of the primary mechanisms for coordinating Federal workforce activities in QIST is through the National Science and Technology Council (NSTC) Subcommittee on Quantum Information Science (SCQIS) **Interagency Working Group on Workforce (IWG-WF).**

This factsheet gives some examples of activities that Federal agencies have engaged in or funded in order to create a quantum-smart workforce for tomorrow. At the **K-12** level, the activities include identifying QIST concepts and integrating them into existing K-12 courses, developing and curating approachable quantum lessons and activities, providing professional development for teachers, and engaging in public outreach about QIST and QIST careers. For **undergraduate** and **graduate** students, the activities increasingly involve scholarships, fellowships, and research opportunities, while providing additional on-ramps to QIST through summer schools. For **postdoctoral** scholars and **professionals**, activities include fellowships, summer schools, research opportunities, and funding for institutions traditionally underrepresented in the Federal research portfolio.

See quantum.gov for more information

Learn More
www.quantum.gov

OSTP-NSF Quantum Computer Cybersecurity Workshop 9/22

NQI Centers Meeting @ WH 12/22

NQI Advisory Committee (Federal Registry Notice Dec 16)

International engagement

New Bilateral Quantum Statements

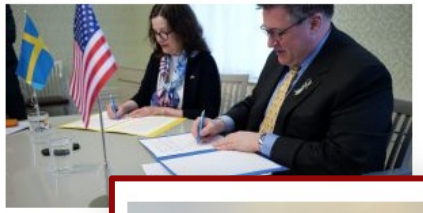
INTERNATIONAL

The United States and Finland Move to Strengthen Cooperation in Quantum

On April 5, the United States and Finland signed a Joint Statement on

logy,

on in the



INTERNATIONAL

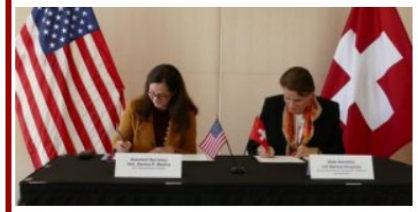
The United States and Sweden Sign Quantum Cooperation Statement

Photo by Ulrika Westerberg at the Government Offices of Sweden. On

INTERNATIONAL

The United States and Denmark Take Steps to Strengthen Quantum Cooperation

(June 8, 2022) Following the June 3 meeting between the United



INTERNATIONAL

The United States and Switzerland Sign Joint Statement to Strengthen Collaboration on Quantum

(October 19, 2022) Today, the United States and Switzerland signed a Joint Statement on Cooperation in Quantum Information Science and Technology (QIST) at the Embassy of Switzerland in Washington, DC. ...

Multilateral quantum dialogues

May 2022

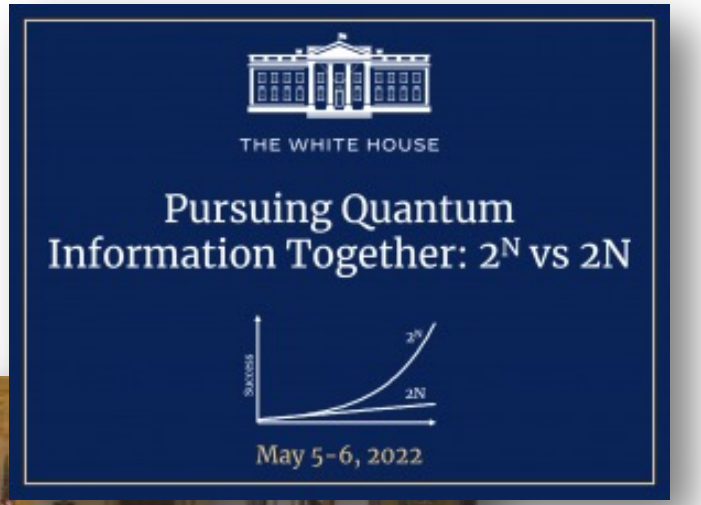
Nov 2022

AUKUS

QUAD

NATO (DIANA)

....



Agency actions

ear Colleague Letter: International Collaboration upplements in Quantum Information Science and ngineering Research

INTERNATIONAL / NSF / R&D FUNDING OPPORTUNITIES

NSF Funding for International Collaboration in Quantum

(August 18, 2022) The National Science Foundation (NSF) released a Dear Colleague Letter on July 21, 2022 on International Collaboration Supplements in Quantum Information Science and Engineering Research. With this ...

Live on entanglementexchange.org

Entanglement Exchange

The development of the next generation of scientists and engineers benefits humanity and is necessary to expand the field of quantum information science and technology. The Entanglement Exchange represents a commitment to facilitate this exchange of students, researchers, and professionals in the field.

Quantum is a global endeavor. International cooperation and collaboration through people exchanges are key to combine the expertise, ingenuity, and creativity of all people to expand humanity's fundamental understanding of quantum information and thereby accelerate the realization of new technologies for the benefit of society.

These partnerships begin with personal experiences. The Entanglement Exchange represents a beginning step in creating more opportunities to work alongside each other from joint graduate fellowships to postdoctoral opportunities to visits and sabbaticals.

This website links to Entanglement Exchange pages hosted by several countries. Each page will be maintained to help individuals looking for international research experiences, both inward and outward, to or from the respective quantum ecosystems.

Australia
Canada
Denmark
Finland
France
Germany
Japan
Netherlands
Sweden
Switzerland
United Kingdom
United States

NEWS

11/30/2022 - Entanglement Exchange Links Quantum Researchers Across Twelve Nations

Entanglement Exchange Links Quantum Researchers Across Twelve Nations

New website is a portal for international exchange opportunities in quantum information science

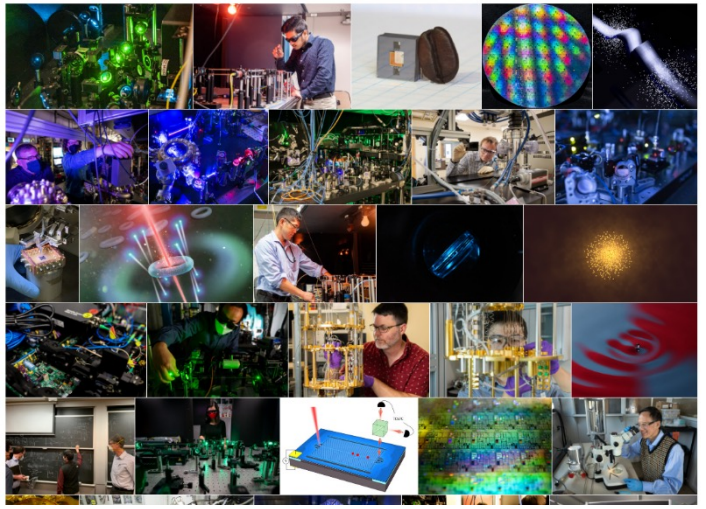
November 30, 2022

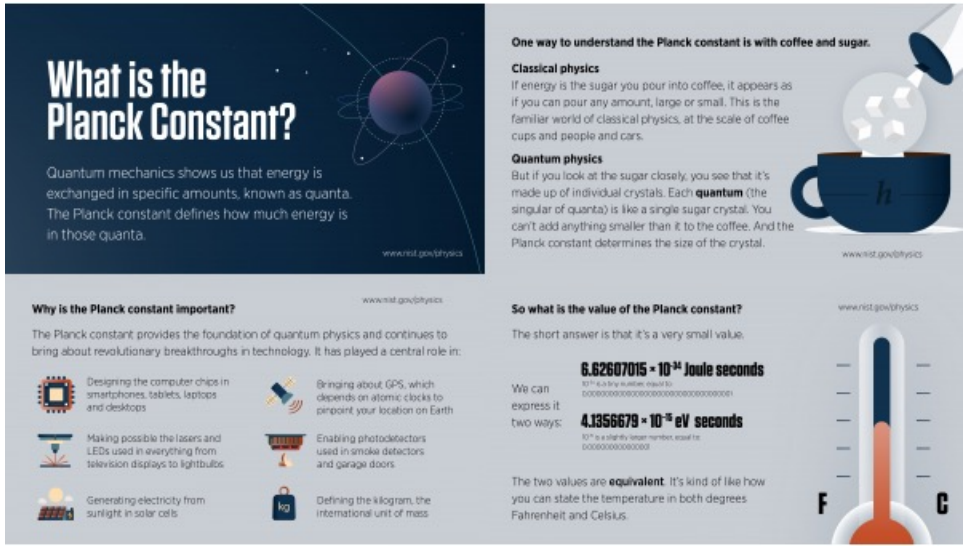
Australia, Canada, Denmark, Finland, France, Germany, Japan, the Netherlands, Sweden, Switzerland, the United Kingdom, and the United States are proud to launch the Entanglement Exchange, a portal for highlighting international exchange opportunities for students, postdocs, and researchers in quantum information science (QIS).

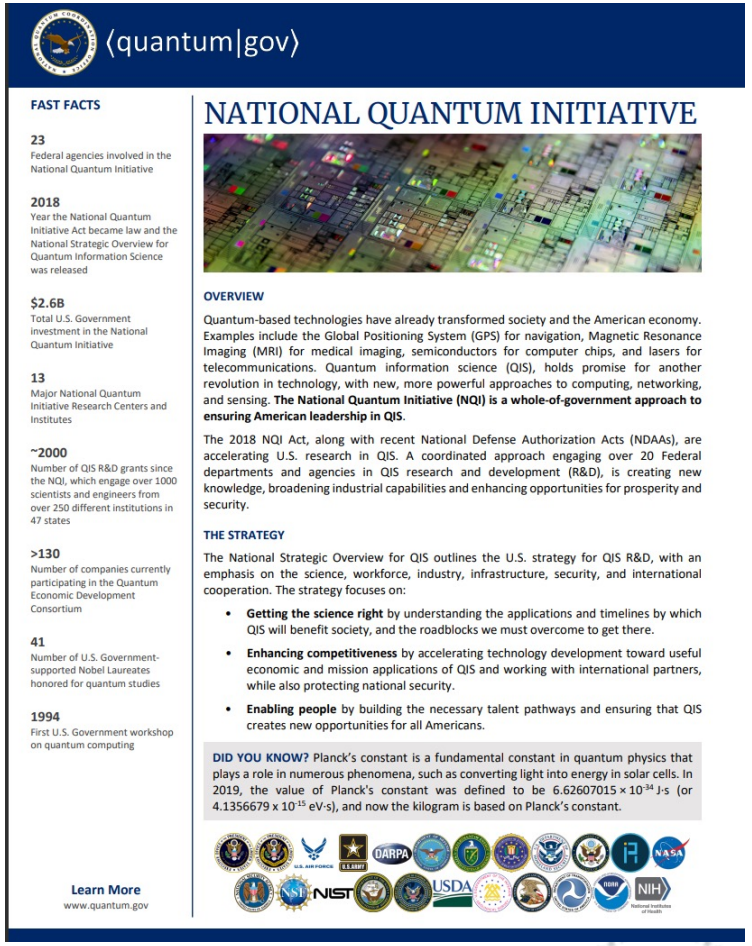
QIS is an emerging field that harnesses quantum physics for information processing, and it promises technological breakthroughs such as quantum computers, quantum networks, and quantum sensors, each of which offer capabilities beyond traditional devices. The field has been developing for decades, but in recent years, the pace of discovery has accelerated through programs and initiatives to invest in QIS research and development.

In May 2022, a roundtable meeting on Pursuing Quantum Information Together was held in Washington between the twelve countries. This meeting highlighted the importance of international cooperation in QIS to accelerate discovery, share resources, and jointly address global challenges. Recognizing the benefits of international partnerships and the global nature of science, the idea for the Entanglement Exchange was proposed as a follow-up action.

Working together, the countries identified exchange opportunities in QIS and developed the Entanglement Exchange to help distribute information about those opportunities. In November 2022, the countries







Thanks to all that contributed to make this a success!!!

Quantum in CHIPS & CHIPS for Quantum

Quantum in the CHIPS and Science Act of 2022

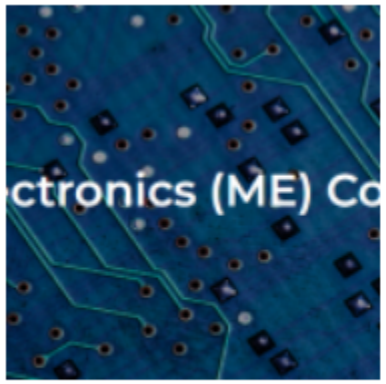
(8/9/2022)

NQIA, QIS Budget

(August 9, 2022) Ensurir
science right, enhancin
created by this new fiel

Quantum-specific programs authorized by the CHIPS and Science Act	Lead Agencies	Annual Authorization of Appropriations	Timeframe
Quantum Science Network	DOE	$100,000,000	2023-2027
Quantum User Expansion for Science and Technology Program	DOE	$30,000,000*	2023-2027
Quantum Networking and Communications Research and Standardization	NIST	$15,000,000	2023-2027
Next Generation Quantum Leaders Pilot Program	NSF	$8,000,000	2023-2026
Annual Authorized Investment		$153,000,000	

+ authorizations for $++ for NSF, DOE, …



DoD Funding for Prototyping Quantum Technologies

(9/19/2022)

Infrastructure, R&D Funding Opportunities

(September 19, 2022) The Office of the Undersecretary of Defense, Research & Engineering (OUSD(R&E))'s Microelectronics program will soon be supporting domestic prototyping capability in six application areas, including quantum technology. The end-state goal to develop a national network of regional innovation…

Considering opportunities for QIST in the implementation of the CHIPS Act

Report from the National Quantum Initiative Advisory Committee

- *Renewing the National Quantum Initiative: Recommendations for Sustaining American Leadership in Quantum Information Science*
- Available at https://www.quantum.gov/about/nqiac/

1. Reauthorize and appropriate the NQI Act
2. Expand research
3. Fund industry-led partnerships
4. Invest in equipment and infrastructure
5. Promote international cooperation
6. Promote and protect U.S. QIST R&D
7. Strengthen supply chains
8. Develop domestic talent
9. Attract and retain foreign talent

NQIAC & NQCO

House Science Committee Hearing on the NQI

- On June 7, 2023, the House Committee on Science, Space, and Technology (HSST) held a full hearing on *Advancing American Leadership in Quantum Technology*.

1. **Reauthorize the NSF and DOE quantum information science research and education centers**
2. **Expand and broaden participation in quantum information science**
3. **Expand the authorized core agencies: STATE, NIH, NASA, DHS, DOD/IC**
4. **Begin translating discoveries in quantum information science to commercial utility and agency missions.**
5. **Prioritize funding to upgrade the aging infrastructure of laboratory facilities.**

COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
CHAIRMAN FRANK LUCAS

FULL COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HEARING CHARTER

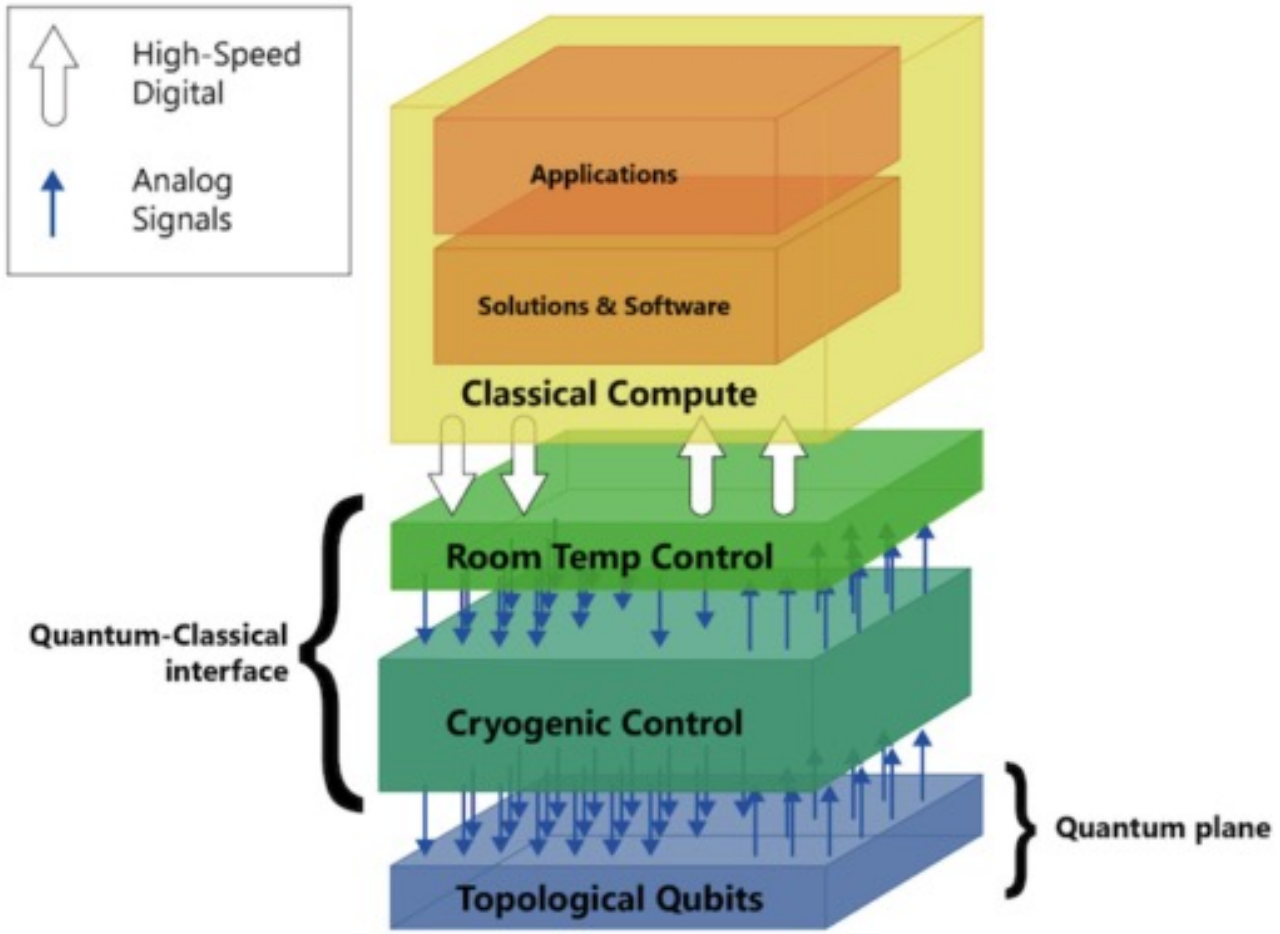
"Advancing American Leadership in Quantum Technology"

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

https://science.house.gov/2023/6/full-committee-hearing

Quantum is more than Quantum Physics

- The future of information processing is *different*
- QC's are one example
- And representative of others (AI accelerators, beyond-Moore, etc.)
- Exotic materials, packaging, operating regimes, ...
- **The skillsets needed are applicable broadly to other industries of the future**



https://www.microsoft.com/en-us/research/publication/a-cryogenic-cmos-chip-for-generating-control-signals-for-multiple-qubits/

Quantum.gov