U.S. DEPARTMENT of ENERGY | Office of Science

JULY 17, 2026

SCAC QUANTUM SUBCOMMITTEE **REPORT**

Anna Grassellino, FNAL – on behalf of the SCAC QIS Subcommittee

Outline

- Charge to the Quantum Subcommittee
- Committee Process
- Findings and Rigorous Assessment
- Roadmap
- Draft Recommendations

Special thanks to Samantha Koch (FNAL) and Hannah Adams (FNAL) for their contributions to the graphics and presentation design.

Committee Members

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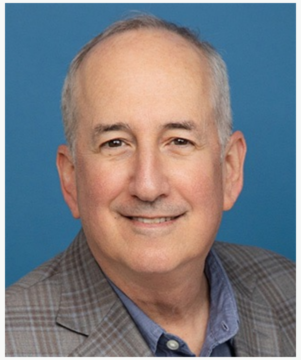

Eric Isaacs
RCSA

Mark Papermaster
AMD

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UChicago / Argonne

Lara Jehi
Cleveland Clinic

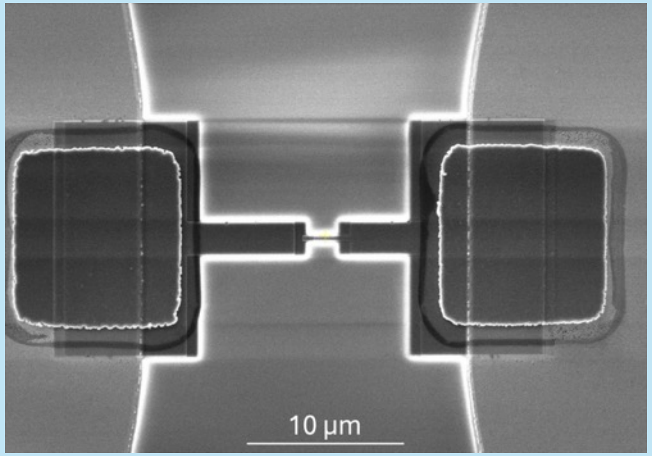
Martin Schmidt
RPI

Tanner Crowder, DOE SC (ASCR)
Designated Federal Officer

Quantum Computing

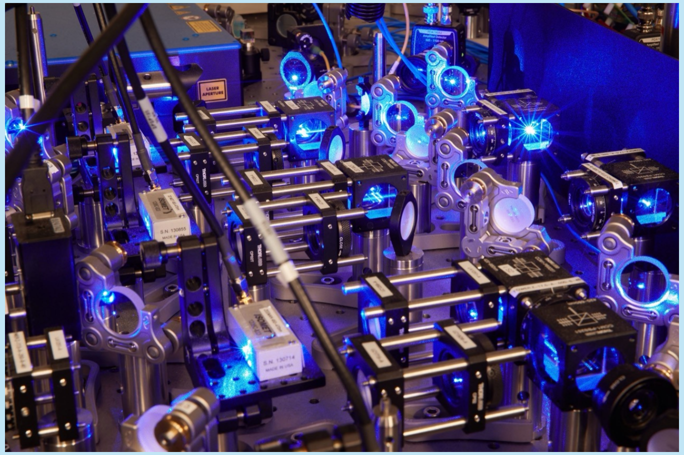
Harvesting fundamental laws of quantum mechanics to enable a new computing paradigm

Pushing the limits of coherence, sensitivity, and control



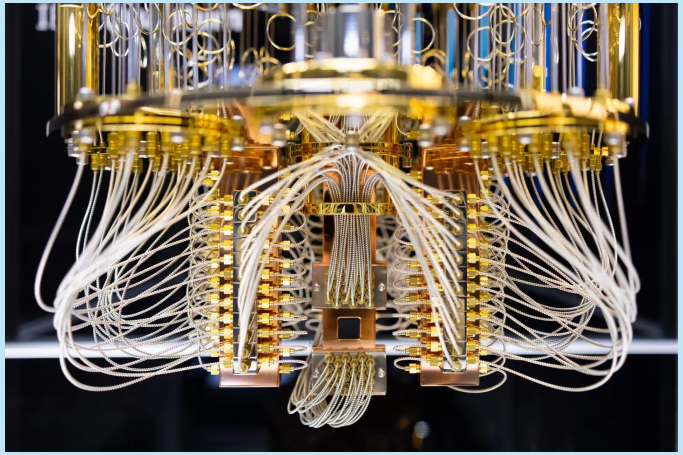
Heart of a sc qubit

Unlocking new regimes of measurement



Neutral Atoms

Approaching Scientific Utility



Superconducting Processor

CHARGE, PROCESS

Charge to the Subcommittee

"I am asking the SC Advisory Committee (SCAC) to form a subcommittee to further study how best to prioritize resources, strengthen U.S. leadership, and accelerate scientific discovery in quantum computing by **providing a roadmap** to identify the near-term steps to a concrete *2028 goal of an error-corrected quantum computer with sufficient scale to enable revolutionary scientific advances*."

"The roadmap should include a rigorous assessment of the current landscape, identifying critical scientific targets and technical opportunities and gaps, and should suggest **milestone-based investments**."

"The subcommittee's work should consider opportunities to create **public-private partnerships** leveraging DOE capabilities, private sector advances, and other agency resources to maximize impact."

"The subcommittee shall provide an assessment of the current landscape and a near-term roadmap by July 2026 to the SCAC *for deliberation* based on the subcommittee's expertise and inclusive and **broad stakeholder input**. "

https://science.osti.gov/-/media/About/pdf/scac/reports/Charge-to-SCAC---Quantum_S4-Gil-Signed.pdf

Charge to the Subcommittee

"The subcommittee's work may involve making recommendations about infrastructure and facilities needs relevant for quantum computing applications; the subcommittee shall coordinate with the SCAC or any subcommittees thereof (i.e., the Facilities Subcommittee) that are charged with making recommendations about SC's facilities needs."

UPDATE: The Quantum Subcommittee will meet with the Facilities Subcommittee on **August 10** to discuss findings and recommendations as they pertain to quantum facilities needs.

The subcommittee interpreted the charge as developing the roadmap to the 2028 goal as a steppingstone to future DOE capabilities.

https://science.osti.gov/-/media/About/pdf/scac/reports/Charge-to-SCAC---Quantum_S4-Gil-Signed.pdf

Timeline & Community Engagement

Executive outreach. Broad participation. A roadmap shaped by the quantum community.

COMMITTEE TIMELINE (April–July 2026)

April 30, 2026
Kickoff Meeting
Charge review, goals, approach, and workplan finalized

Early May 2026
Community Input Request (CIR) Released
Public CIR open for ~2 weeks to solicit written input

May 2026
Stakeholder Interviews
~40 interviews with industry, academia, labs, agencies & international partners

June 1–5, 2026
Select Town Hall Speakers
Finalize agenda and invite speakers across the ecosystem

June 12, 2026
Community Town Hall
One-day virtual Town Hall with broad community participation

June 13–July 10, 2026
Synthesis & Deliberations
Analyze input, identify consensus, divergences, and develop roadmap and recommendations

Mid-July 2026
Report to SCAC
Final report presented to SCAC in Washington, DC

Community & Stakeholder Engagement

STAKEHOLDER INTERVIEWS

40
one-hour interviews

Industry leaders, NQISRC Directors, federal agencies, national labs, academia, and international partners

COMMUNITY INPUT REQUEST

>100
written submissions

Researchers, developers, scientists, programs, and organizations from across the U.S. and internationally

COMMUNITY TOWN HALL

400+
registered participants

Broad representation across hardware, software, applications, science domains, and policy

TOTAL PARTICIPATION

500+
individuals engaged

Hundreds of unique perspectives informing the roadmap and recommendations

DIVERSE & GLOBAL INPUT

6
countries

across academia, industry, national labs, government, and non-profits

STAKEHOLDERS ENGAGED

INDUSTRY
Quantum hardware companies, software firms, and startups

ACADEMIA
Universities and research institutes

NATIONAL LABS
DOE labs and national research facilities

FEDERAL AGENCIES
DOE SC programs, NIST, NSF, NASA, DARPA, DOD, and others

NQISRCs & CENTERS
Directors and investigators from DOE National Quantum Information Science Centers

USER COMMUNITIES
Chemistry, materials, biology, fusion, HEP, NP, BES, FES, BER, and more

INTERNATIONAL PARTNERS
Global leaders and collaborating institutions

EARLY CAREER
Researchers, trainees, and students

Stakeholder Interviews

Gambetta
IBM

Monroe
IonQ / Duke

Lukin
Quera / Harvard

Martinis
Qolab

Painter
Amazon

Schoelpkof
D-Wave / Yale

Reagor
Google

Bestwick
Rigetti

Shaboldt
PsiQuantum

Humble
ORNL

Murthy
FNAL

Bacon
Google

Motta
IBM

Babbush
Google

Chan
Caltech

Savage
UWashington

Munoz Ramo
Quantinuum

Lykken
FNAL

Vallecorsa
CERN

Calarco
Jülich

de Jong
LBNL

Holt
ANL

Mason
LANL

McGill
Sandia

Kearns
ANL

Whiterell
Berkeley

Tourassi
ORNL

Holtkamp
FNAL

Sarrao
SLAC

Dilling
JLab

Hill
BNL

Black
BNL

Siddiqi
LBNL

Roadmaps: Subject Matter Expert Contributors

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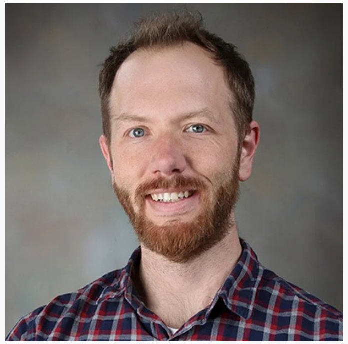

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Salman Habib
ANL

Kenneth Merz
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Travis Humble
ORNL

FINDINGS

FINDING 1

Quantum computing is approaching a historic inflection point, creating an unprecedented opportunity to transform scientific discovery.

- Recent advances in logical qubits, quantum error correction, and system integration indicate that quantum computing is quickly transitioning toward a scientifically useful capability.
- While scientific and engineering challenges remain, the committee concludes that the coming decade presents a unique opportunity to establish quantum computing as a new scientific instrument for discovery.

Approaching Scientific Relevancy

ScienceHighlights

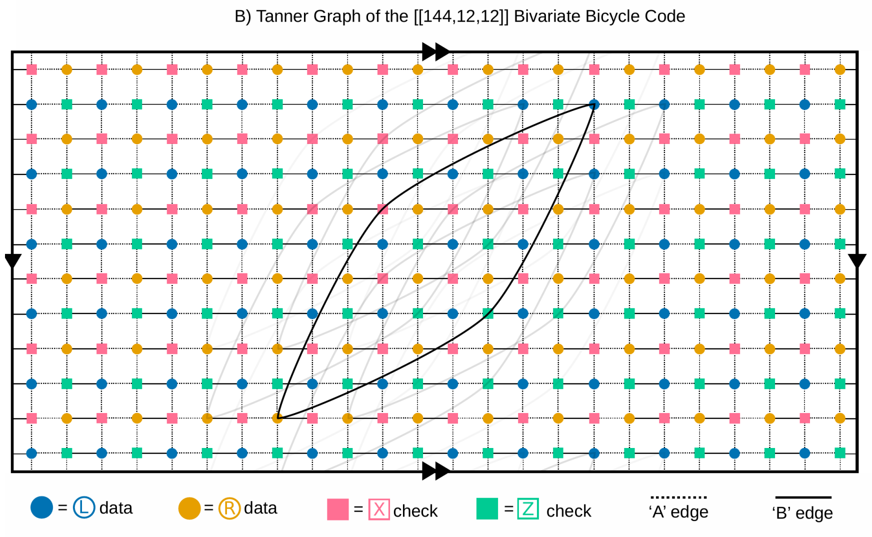
A high-threshold, low-overhead fault-tolerant memory

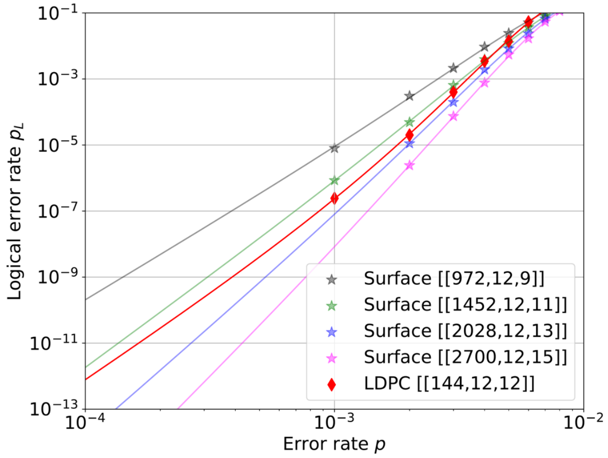
For nearly 20 years the surface code has led quantum error correction, but its low encoding rate demands thousands of physical qubits per logical qubit.

This work introduces quantum LDPC “bivariate-bicycle” codes reaching a **0.8% error threshold** — on par with the surface code — but far more efficiently. The [[144,12,12]] “gross code” protects **12 logical qubits with 288 physical qubits** (vs. ~3000 for the surface code), using only a depth-7 circuit of nearest-neighbor gates.

High-threshold and low-overhead fault-tolerant quantum memory

Nature 627, 778 (2024) · arXiv:2308.07915

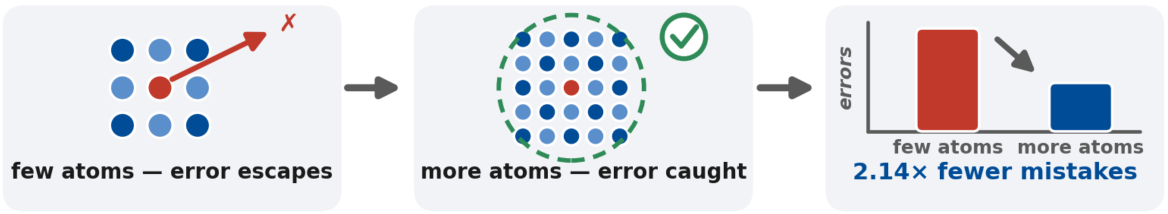




[[144,12,12]] LDPC code matches surface-code suppression with far fewer qubits

Approaching Fault Tolerance

ScienceHighlights

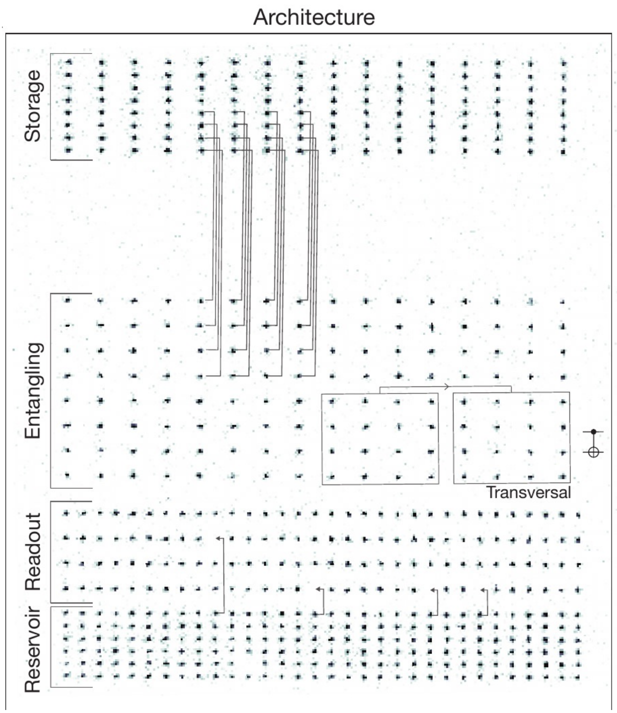


Add more atoms, make fewer mistakes

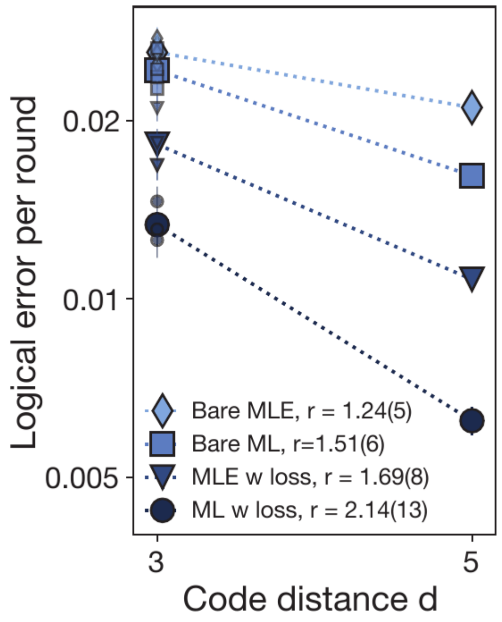
Quantum computers make mistakes, and normally more parts means more mistakes. Error correction promises the opposite — but only past a **threshold**.

Harvard's team crossed it: **448 atoms** in laser tweezers, shuttled between "storage," "entangling" and "readout" zones like an assembly line. Making the safety net bigger cut the errors **2.14×**.

The other essential pieces ran on the same machine, including recycling atoms mid-calculation to go **100× faster** — a first.



448 atoms, sorted into storage, entangling and readout zones



Growing the code (d=3→5) cuts logical error per round 2.14×

A fault-tolerant neutral-atom architecture for universal quantum computation

Nature 649, 39 (2026) · arXiv:2506.20661

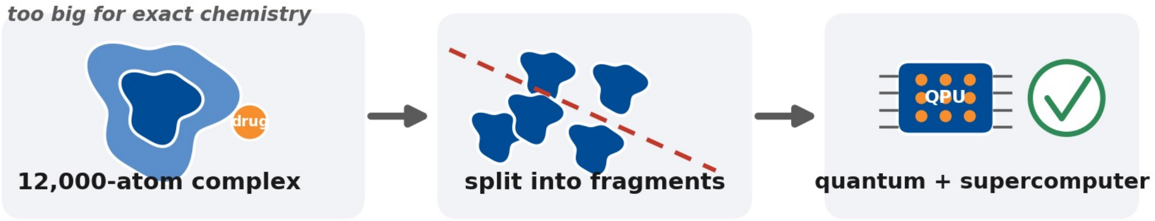
FINDING 2

Scientific utility has become a critical challenge

- The committee found broad consensus that progress should be measured by the ability to solve compelling scientific problems, not by hardware metrics alone.
- Scientific grand challenges should define the requirements for algorithms, software, hardware, AI, and systems engineering through continuous co-design, rather than adapting applications to existing technologies.
- This science-driven approach will accelerate meaningful applications, guide technology development, and build the broad user communities needed for future quantum computing capabilities.

Approaching Scientific Relevancy

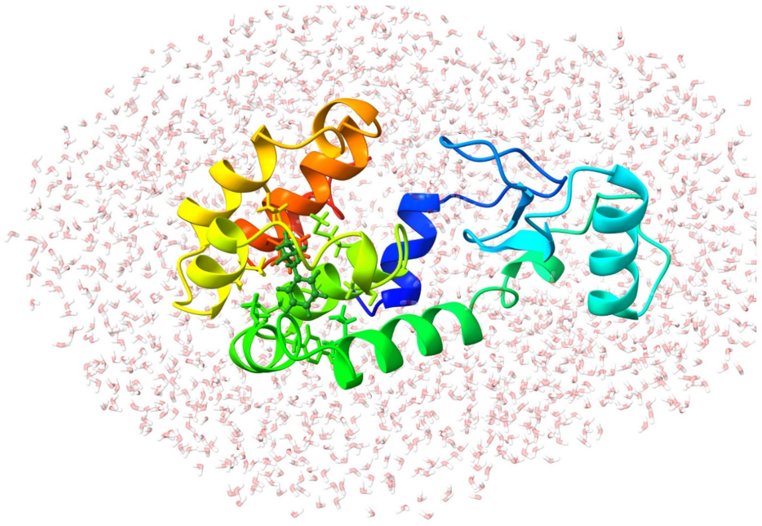
ScienceHighlights

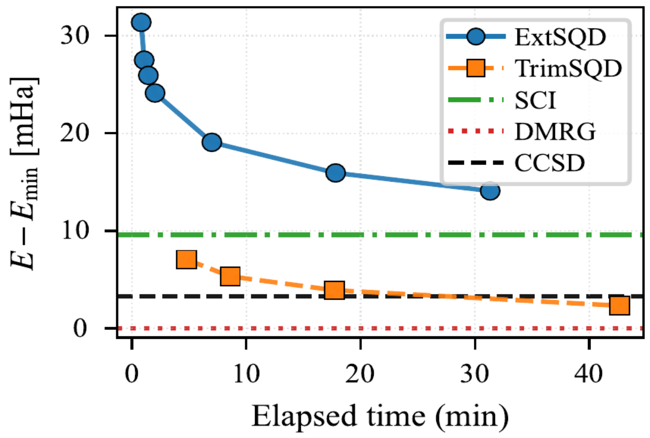


Quantum-classical supercomputing breaks the 12,000-atom barrier

Accurate wavefunction methods describe chemical bonding from first principles, but their steep cost has confined them to small molecules — far short of a full drug–protein complex.

Splitting each protein into fragments, the team sampled their electronic structure on two 156-qubit IBM processors, with the wavefunctions reconstructed on the Fugaku and Miyabi-G supercomputers. The result: two protein–ligand complexes of **11,600 and 12,600 atoms** — a **>40× jump in system size** and up to **210× better accuracy**, on par with gold-standard CCSD.





Crossing the 12,000-atom barrier with heterogeneous quantum-classical supercomputing: quantum chemistry of protein-ligand complexes

arXiv:2605.01138 (2026)

Approaching Scientific Relevancy

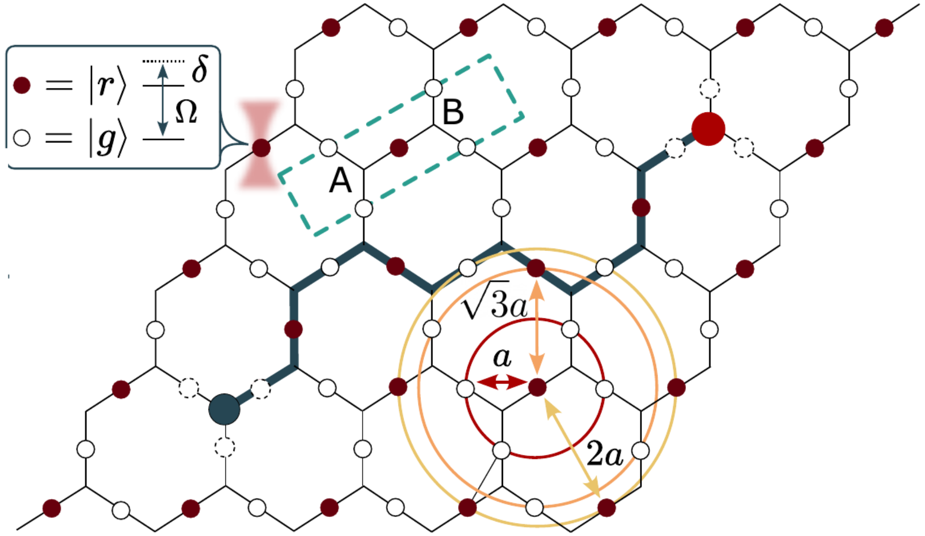
ScienceHighlights

A quantum simulator recreates the “glue” inside matter — now in 2-D

Real particle physics is hard because it lives in more than one dimension, where even supercomputers stall. This simulator runs a true **2-D** version of the theory for the first time — a step toward genuine scientific relevancy.

The picture: quarks are bound like a rubber band that **snaps into new particles** when pulled — seen here on a “Kagome” grid of laser-trapped atoms, in real time.

That same snapping makes the particle sprays at the LHC and colliders beyond it — which machines like this could one day compute from first principles.



Observation of string breaking on a (2+1)D Rydberg quantum simulator

Nature 642, 321 (2025) · arXiv:2410.16558

FINDING 3

DOE is uniquely positioned to lead the next phase of scientific quantum computing.

- DOE has established one of the world's leading quantum research ecosystems through sustained investments in Office of Science core programs, the National Quantum Information Science Research Centers, and partnerships spanning national labs, universities, industry, and international collaborators.
- DOE can further distinguish itself from both commercial cloud providers and international initiatives.
- Several stakeholders highlighted successful efforts in the United Kingdom, Europe, and individual U.S. institutions that place quantum computers within research organizations. The committee believes DOE can go significantly further by applying its longstanding model for developing **major scientific instruments.**
- The committee believes DOE can distinguish itself by applying the same philosophy that has guided its most successful scientific facilities: **science drives instrument design.**

FINDING 4

New partnership models and greater openness are essential to accelerate scientific discovery.

- Across stakeholder interviews, the committee consistently heard that accelerating scientific utility requires deeper collaboration among hardware developers, software and AI researchers, and domain scientists. Existing partnership models should evolve to enable sustained co-design and closer interaction between technology developers and scientific users.
- Stakeholders also emphasized that meaningful co-design requires quantum computing systems to be more than "black boxes."
- While respecting intellectual property and commercial innovation, researchers need sufficient access to hardware architectures, control interfaces, diagnostics, and system performance to optimize scientific applications.
- The committee concludes that new collaboration frameworks should be developed to lower barriers to scientific collaboration while preserving appropriate IP protections.

FINDING 5

Innovation across the quantum technology stack remains essential.

- Investments in foundational quantum technologies remain critical.
- Continuing to scale to fault-tolerant quantum computing will require advances across the entire technology stack, including coherence, error correction, control systems, cryogenics, modular architectures, software, networking, manufacturability, and systems integration.
- The committee further concludes that DOE's unique capabilities in superconductivity, accelerator science, cryogenics, microelectronics, advanced materials, scientific instrumentation, and large-scale engineering provide a strong foundation for continued leadership in quantum technology.

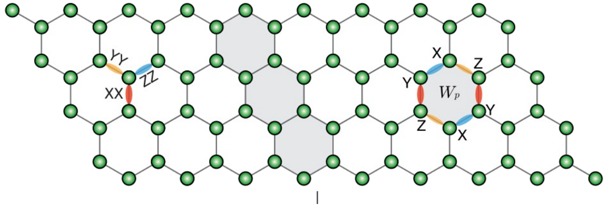
Advancing Enabling Technologies

ScienceHighlights

Tantalum transmon qubits

Millisecond lifetimes and coherence times in 2D transmon qubits
*Nature **647**, 343 (2025)*

Reconfigurable atom arrays



Probing the Kitaev honeycomb model on a neutral-atom quantum computer
Nature 645, 341 (2025)

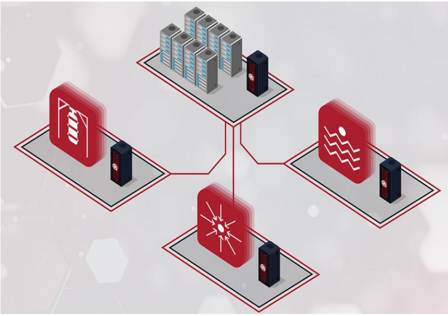
Cavity-qudit platforms

Ultracoherent superconducting cavity-based multiqudit platform with error-resilient control
arXiv:2506.03286 (2026)

Silicon quantum dots testbed

Valley Splitting Correlations Within a Single Silicon Spin Qubit
*Nat. Commun. **16**, 11381 (2025)*

Quantum-HPC integration



Benchmarking quantum simulation with neutron-scattering experiments
arXiv:2603.15608 (2026)

C2QA Co-design Center for Quantum Advantage

QUANTUM SYSTEMS ACCELERATOR Catalyzing the Quantum Ecosystem

SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

Q-NEXT NEXT GENERATION QUANTUM SCIENCE AND ENGINEERING

QUANTUM SCIENCE CENTER

FINDING 6

Sustained national commitment and technology diversity will be essential to realize the full opportunity.

- The committee concludes that the next phase of quantum computing should build upon DOE's successful investments and preserve the broad, competitive ecosystem that has positioned the United States as a global leader.
- While stakeholders expressed differing views on technology timelines and hardware modalities, there was broad consensus that it is premature to converge on a single technological pathway.
- Instead, continued investment across multiple hardware modalities, architectures, and scientific approaches—evaluated through common scientific and technical milestones—will maximize innovation, reduce programmatic risk, and allow scientific utility to guide future evolution.

ROADMAPS

A Three-Dimensional, Phased Roadmap Toward Quantum Scientific Utility

The committee recommends that DOE guide its quantum computing activities through **three complementary and tightly coupled roadmaps** that evolve together, **through three phases.**

- Scientific grand challenges define the capabilities required of future quantum computers; progressively more capable fault-tolerant hardware enables increasingly ambitious scientific demonstrations; and targeted technology demonstrations reduce the principal technical risks across the quantum computing stack.
- Together, these roadmaps provide a common framework for coordinating DOE investments, incentivizing and measuring progress, and informing future decisions. **These activities do not replace, but rather build upon, expand, accelerate, and focus DOE quantum programs.**

SCAC Roadmap: Path to an Integrated Quantum Future

Grand scientific challenges define the requirements. Advances in fault-tolerant systems enable progressively greater scientific impact.

GRAND SCIENTIFIC CHALLENGE	2026 FOUNDATIONAL DEMONSTRATIONS	2027 SCALING LARGER	2028 SCIENTIFIC-RELEVANT DEMO (TRANSITION)	2030+ LONG-TERM BREAKTHROUGH	IMPACT WHY IT MATTERS (Scientific & Societal)
DESIGNING NEW MEDICINES & BIOLOGICAL TOOLS	Calculate few active sites, molecular fragments, and photoactive molecules	Simulate excited states and protein–ligand interactions	Chemically accurate prediction of a selected protein–ligand or enzyme active site	Predict interactions and photochemical behavior to design new medicines and diagnostics	• Faster drug discovery and reduced cost • New diagnostics and precision medicine
TRANSFORMING CHEMICAL MANUFACTURING & CATALYSIS	Calculate strongly correlated bonds and small catalytic centers on clusters	Simulate steps in catalytic reactions on transition metals and metalloenzymes	Resolve a key reaction step in an industrial catalyst with chemically meaningful accuracy	Design catalysts, enzymes, and reaction pathways from first principles for fuels and chemicals	• Clean, efficient chemical production • New pathways for fertilizers, fuels, and advanced materials
DISCOVERING NEXT-GENERATION MATERIALS & SUPERCONDUCTORS	Simulate simple materials models that reproduce experiments	Extend to more complex models relevant to correlated materials	Produce a quantum-validated effective model or prediction for a correlated material	Predict and design superconductors, energy-storage materials, etc. before fabrication	• Better batteries and electronics • Accelerated materials innovation
ENABLING PRACTICAL FUSION ENERGY	Calculate tritium binding, simple plasma-response models, or transport in materials	Calculate rates, conductivities, and tritium behavior in candidate materials	Deliver a validated prediction of key quantities limiting fusion design	Simulate integrated tritium production and recovery, plasma-facing materials, extreme dynamics for reactor and target design	• More reliable fusion systems • Faster path to commercial fusion energy
REVEALING THE LAWS OF NUCLEAR MATTER & NEUTRINOS	Simulate the impact of neutrinos on light nuclei & the equation of state of nuclear models	Extend to light and medium nuclei, and more realistic models	Demonstrate a nuclear response to neutrinos for experiments and low-density QCD equations of state	Predict nuclear responses for argon and neutron star density equations of state	• Better interpretation of DUNE, LIGO, Mu2e • Understand the strong force and neutrinos
REPLAYING THE BIG BANG	Simulate simplified models of dynamics of dense quark and gluon matter	Particle-spray formation and quark-matter flow	First phenomenological inputs to event generators	First-principles collider inputs; the early-universe plasma	• Discover the fundamental laws of nature • Extending reach of LHC, EIC, and exploration of the early universe

PHASE 1: QUANTUM CHALLENGES (2026-2028)
Build and scale capabilities through milestone-driven challenges across priority scientific domains

PHASE 2: USER FACILITY (IF WARRANTED) (2028+)
Enable mission-driven science through an integrated Quantum Computing User Facility.

PHASE 3: INTEGRATED FUTURE (2030+)
Quantum computing integrated across the DOE scientific enterprise for transformational impact.

Quantum System Capability Progression

(Illustrative Ranges Across Platforms)

	2026 VERIFIED DEMONSTRATIONS	2027 SCALABLE SYSTEMS	2028 SCIENTIFIC-RELEVANT DEMONSTRATIONS	2030+ USER FACILITY CAPABILITY
LOGICAL QUBITS	~1 – 10 logical qubits	~10 – 50 logical qubits	~50 – 100+ logical qubits	~1,000 – 10,000 logical qubits for transformative campaigns
HARD LOGICAL OPERATIONS (Approximate)	Up to ~10^4 quantum operations in tightly controlled demonstrations	~10^3 – 10^4 hard logical operations	~10^4 – 10^5 hard logical operations	~10^9 – 10^{10} hard logical operations for large scientific applications
ACCURACY & RELIABILITY	Logical operations demonstrated and classically benchmarked	Lower logical error rates; repeatable multi-logical-qubit workflows	Reliable fault-tolerant execution sufficient for end-to-end scientific calculation	Production-level reliability for sustained scientific campaigns
SYSTEM INTEGRATION	Early logical-qubit demonstrations	Integrated control, decoding, software, and calibration	End-to-end quantum–HPC–AI workflow with scientific validation	Facility-scale orchestration, automated error correction, data services, user support
SCIENTIFIC VALIDATION	Direct classical verification	Classical verification or high-quality emulation where feasible	Independent validation against experiment, classical limits, or predictive scientific value	Results beyond routine classical reach, integrated with experiments and DOE user facilities

Technology Demonstration Roadmap

Technology demonstrations de-risk the path to large-scale fault-tolerant quantum computing by addressing critical bottlenecks across the full stack. Milestones should be quantitative, reproducible, and architecture-agnostic, demonstrating that enabling technologies are mature, manufacturable, and integrable at scale.

	2026	2027	2028	2030+	OUTCOME
QUBIT & QUDIT QUALITY COHERENCE, LOSS & FIDELITY	Hold a two-qubit error $\leq 10^{-3}$ system-wide	Cut that error rate threefold, to $\leq 3\times10^{-4}$ across $\geq$100 qubits operated together	old $\leq 3\times10^{-4}$ across 1,000 qubits, with $\geq$ 99.9% working at any time	**MOONSHOT:** $\leq 10^{-4}$ error across 10^6–10^7 qubits	High-fidelity qubits with error rates low enough for large-scale error correction
ERROR CORRECTION & LOGICAL QUBITS	Show both error types fall exponentially as the code grows, with $\geq$6× suppression	Run a real algorithm on $\geq$5 error-corrected qubits that beat the raw hardware	Reach $\leq 10^{-6}$ error per logical operation, with real-time correction	**MOONSHOT:** 10^3 to 10^4 error-corrected qubits sustaining 10^9 operations in a single scientific campaign, at 1 error in 10^{10}	Validated error correction that suppresses errors exponentially with scale
CONTROL & READOUT SYSTEMS	Fix errors in real time while the computation runs, on $\geq$100 qubits	Run 1,000 or more qubits from one control system, with simultaneous operation increasing gate errors by no more than a factor of two	Measure qubits mid-calculation with 99.9% accuracy across every qubit of a 1,000-qubit machine, inside a closed error-correction loop	**MOONSHOT:** run 10^6 to 10^7 qubits as one machine, decoding 10^{12} bits per second with under 5 megawatts of control power	Scalable, low-latency control and readout enabling fault-tolerant operation
ENABLING INFRASTRUCTURE & SYSTEM INTEGRATION	Publish the measured plant budget per qubit for cooling, wiring, laser power and rack space at today's largest operating size, and show 10x headroom	Show that heat, vibration, and electrical and optical noise do not push the machine above the error margin required this year	Build and run the plant sized for 10^4 qubits, with measured power per qubit at most half that of the 1,000-qubit system	**MOONSHOT:** a scheduled national user facility with 10^3 to 10^4 error-corrected qubits, 95% annual availability, months between serious faults, and under 10 megawatts of power.	Infrastructure capable of reliably supporting large-scale quantum systems

Technology Demonstration Roadmap

Technology demonstrations de-risk the path to large-scale fault-tolerant quantum computing by addressing critical bottlenecks across the full stack. Milestones should be quantitative, reproducible, and architecture-agnostic, demonstrating that enabling technologies are mature, manufacturable, and integrable at scale.

	2026	2027	2028	2030+	OUTCOME
MODULAR ARCHITECTURES & CONNECTIVITY	Link two separately built modules with an entangling operation across the join above 99% fidelity and a gate time no more than 10× the local gate time	Operate three or more modules as one computer. Replace a failed module and resume error-corrected operation within 24 hours, without interrupting the others	Perform an error-corrected logical operation across a module boundary on a 1,000-qubit machine, with link error no more than 10 times the local gate error	**MOONSHOT:** 100 or more interchangeable, field-replaceable modules totalling 10^6 to 10^7 qubits, in which the joins are as good and as fast as the chips, and the machine never fully warms up	Modular, connected, and serviceable architectures enabling scalable systems
SOFTWARE, COMPILERS & ALGORITHMIC TOOLS	Predict a scientific algorithm's qubit count and runtime before running it, then match the measured hardware result within a factor of two	An external team that did not build the machine compiles and runs a standard benchmark on error-corrected hardware, using only the public toolchain	The same unmodified scientific program runs on two different kinds of quantum computer, with predictions of cost and accuracy correct to within 30%	**MOONSHOT:** one open toolchain compiles and runs a 10^9-operation scientific campaign on 10^3 to 10^4 error-corrected qubits, with its predictions accurate before the machine is switched on.	Software stack ready for fault-tolerant quantum applications at scale
MANUFACTURING & SUPPLY CHAIN	Show that at least half of the parts made meet a published spec, measured across three consecutive production runs with none excluded	Report post-assembly yield against the 2026 pre-assembly figure, across at least three build runs, using unselected components	An audited, measured cost per qubit for the 10^4-qubit plant build, and a second qualified supplier for every critical component	**MOONSHOT:** a U.S. industrial base delivering 10^6 to 10^7 qualified qubits, dual-sourced, at a cost per qubit low enough to build and refresh a national facility.	Manufacturable, reliable, and cost-effective supply chain for scaling
RELIABILITY, DIAGNOSTICS & OPERATIONS	Run error-corrected circuits continuously for 7 days with no human recalibration or tuning, holding the logical error rate within a factor of two throughout.	Run 14 days unattended while continuously error-correcting	One continuous 90-day scientific campaign at 99% availability, on 1,000 error-corrected qubits	**MOONSHOT:** three years of hands-off operation at 99% uptime, absorbing component failures without losing the calculation	Reliable, maintainable systems ready for facility operations

Planning the Path to a DOE Quantum Computing User Facility

- The committee recognizes that determining the appropriate timing, scale, and scope of a DOE Quantum Computing User Facility require careful evaluation as quantum technologies and scientific applications mature.
- The decision should not be based solely on achieving a specific logical-qubit target, but rather on whether the available capabilities collectively enable scientifically compelling user programs, reliable operation, and a sustainable path for future growth.
- *The committee therefore recommends that DOE establish a dedicated planning activity, working in parallel with the Quantum Challenges Phase, to periodically assess scientific readiness, technology maturity, projected hardware evolution, user demand, facility concepts, operational models, and project implementation options.*
- This planning effort should engage representatives from the Office of Science programs, the National Quantum Information Science Research Centers, national laboratories, universities, industry, and the prospective user community.

Planning the Path to a DOE Quantum Computing User Facility

Among the questions DOE should address with such activities are:

- What minimum level of fault-tolerant capability should the national scientific user facility aim for?
- Should an initial facility be deployed as soon as scientifically useful systems become available, or should DOE wait for larger-capability systems?
- How should facility scope, expansion pathways, and technology refresh strategies be designed to accommodate the rapid evolution of quantum technologies?
- What scientific applications, user demand, operational concepts, and partnerships should define the facility from its inception?

By beginning this planning process early, DOE can ensure that, as soon as the scientific and technical milestones are achieved (possibly in 2028), the Department is prepared to make timely, evidence-based decisions regarding the scale, implementation, and evolution of a Quantum Computing User Facility.

Toward an Integrated Quantum Future

- Successful demonstration of scientific utility may justify a **DOE Quantum Computing User Facility** that provides broad user access to advanced quantum computing capabilities.
- At the same time, the committee expects that many quantum technologies will naturally become embedded throughout the DOE scientific enterprise.

- **Depending on the scientific mission, these capabilities may range from a large-scale user facility to smaller-scale quantum processors, specialized quantum simulators, quantum-enhanced instruments, distributed sensor arrays, or embedded quantum systems integrated directly within experimental facilities.**

Toward an Integrated Quantum Future

- The committee envisions a future potential **portfolio of complementary instruments**, each advancing different technological pathways and scientific missions. **Subject to technical and scientific rigorously validated progress and future budgetary considerations**, multiple instruments and locations could ultimately emerge, potentially centered at different DOE National Laboratories, each pursuing complementary objectives such as:
  - different hardware modalities (superconducting circuits, neutral atoms, trapped ions, photonics, spin qubits, and future emerging technologies);
  - different architectural concepts (modular systems, heterogeneous quantum-HPC integration, distributed quantum computing);
  - different scientific priorities (chemistry, materials, particle physics, nuclear physics, optimization, quantum-enhanced experiments);
  - and different models for integrating AI, HPC, networking, and scientific instrumentation.
- The committee envisions these efforts as both competing and complementary components of a national quantum ecosystem that collectively maximize scientific impact while preserving technological diversity.

DRAFT RECOMMENDATIONS

For discussion and endorsement by the SCAC

RECOMMENDATION 1

Build on DOE’s leadership in quantum information science through a phased quantum computing initiative.

- The committee commends DOE for establishing one of the world's leading quantum research ecosystems through sustained investments. Building on this foundation and aligning with the goals of **Quantum Genesis**, the committee recommends launching a phased quantum initiative to accelerate progress toward scientifically useful fault-tolerant quantum computing for scientific discovery.
- **Phase I – Quantum Grand Challenges**
- **Phase II – DOE Quantum Computing User Facility (when milestones met)**
- **Phase III – Integration Across the DOE Scientific Enterprise**

These phases build upon and proceed in parallel with DOE Quantum Research Programs.

PHASE 1: QUANTUM CHALLENGES (2026-2028)
Build and scale capabilities through milestone-driven challenges across priority scientific domains

PHASE 2: USER FACILITY (IF WARRANTED) (2028+)
Enable mission-driven science through an integrated Quantum Computing User Facility.

PHASE 3: INTEGRATED FUTURE (2030+)
Quantum computing integrated across the DOE scientific enterprise for transformational impact.

RECOMMENDATION 2

Establish Quantum Grand Challenges and invest in scientific applications and co-design.

- The committee recommends establishing **DOE Quantum Grand Challenges**, a series of multidisciplinary, milestone-driven, **challenge competitions**, to accelerate the path toward demonstrating a scientifically relevant, error-corrected quantum computing capability by 2028. During this phase DOE should maximally leverage all its momentous quantum initiatives.
- In this phase, DOE should explore and utilize **novel and creative partnership mechanisms** and incentives for National Laboratories, universities, and industry to compete to demonstrate important **scientific applications** of quantum computers via **co-design** of hardware, algorithms, software, systems, and applications teams.
- The committee believes that this phase should serve not only as a rigorous, milestone-driven, competitive framework for advancing quantum technologies and informing the design of the future QCUF, but also as a catalyst for mobilizing the Nation's quantum ecosystem around shared scientific goals.

RECOMMENDATION 3

Establish new partnership models for co-design and lower IP barriers.

- The committee recommends that DOE establish new partnership models that enable sustained, in-person co-design among quantum hardware developers, algorithm researchers, AI experts, software developers, and domain scientists.
- Throughout the stakeholder interviews, one message emerged consistently: **scientific progress depends on bringing users to quantum computers as well as bringing domain scientists and hardware developers together.**
- The committee recommends **DOE convene a community-based working group** — spanning DOE, the National Laboratories, industry, and academia — to establish the shared alignment of purpose and to resolve practical mechanisms such as interconnect standards to enable rapid R&D of multiple modalities and accelerate innovations, handling intellectual property for any joint development, and cost-sharing.

RECOMMENDATION 3 - CONTINUED

Establish new partnership models for co-design and lower IP barriers.

- The committee therefore recommends that DOE explore new mechanisms that enable even deeper integration between National Laboratories, industry, and academia, including:
  - *embedded co-design fellowships: 6-18 months residencies placing domain scientists inside hardware companies' engineering teams and industry teams inside National Labs.*
  - *joint appointments between industry and laboratories;*
  - *shared technical staff;*
  - *hardware deployment at DOE labs and personnel exchanges, leveraging in-kind contributions;*
  - *shared pre-competitive prototypes where industry, laboratories, and universities jointly develop and evaluate quantum technologies' quality and scaling;*
  - *milestone-based DOE-industry co-investments tied to scientific outcomes.*

These partnership models should become a defining characteristic of the Quantum Challenges Phase.

RECOMMENDATION 4

Strengthen Quantum Information Science's role as an integral component of the DOE Office of Science research enterprise.

- Identifying and developing the important science problems that will benefit from quantum computing is a major need as well as an opportunity since it plays to the strengths of DOE national laboratory scientists, academia and DOE Office of Science program objectives.
- The committee therefore recommends that **DOE prioritize embedding quantum across all of the relevant Office of Science programs.** As an immediate step, the committee encourages DOE to maximally leverage its existing Office of Science relevant programs, by providing opportunities and incentives for domain scientists to explore how quantum computing can transform their scientific disciplines, and how their unique capabilities can transform quantum computing.
- **Expanding quantum-focused activities within existing programs** will rapidly grow the scientific user community, accelerate application development, and help define the requirements for the future Quantum Computing User Facility.

RECOMMENDATION 5

Broaden investments across the quantum technology stack.

- The committee recommends that DOE broaden investments across the quantum computing technology stack and de-risking enabling technologies. The DOE National Quantum Information Science Research Centers play a key role in this area.
- Research areas of continued focus and priority – instrumental to achieving the aggressive 2028 goals – include increasing coherence and reducing error rates; understanding and mitigating noise mechanisms and sources of decoherence; developing new materials and processes; scalable control electronics, cabling and cryogenic systems; advancing modular and heterogeneous architectures, packaging and manufacturability, quantum interconnects, software infrastructure, and real-time quantum error correction and decoding.
- The committee further recommends expanding research at the interface between quantum computing and quantum sensing.
- The committee recommends that DOE fully leverage its existing scientific and technology capabilities – including accelerator and detector technology, superconducting and cryogenic systems, microelectronics, advanced materials, scientific instrumentation, and large-scale engineering – to accelerate the development of quantum computing.

RECOMMENDATION 6

Sustain national investment commensurate with the opportunity.

- The committee commends DOE for establishing one of the world's leading quantum research ecosystems through sustained investments in the Office of Science core research programs, the NQISRCs, and partnerships across the ecosystems. The next phase should build upon these investments.
- The committee recommends that DOE and Congress provide broadened investments, commensurate with the scale and strategic importance of the emerging opportunities.
- Realizing the vision presented in this report will require resources beyond those currently available.

RECOMMENDATION 6 - CONTINUED

Sustain national investment commensurate with the opportunity.

- Near-term actions, including expanding quantum activities within existing Office of Science programs, can accelerate progress and broaden participation across the scientific community, but they should complement – not replace – dedicated and increased investments in quantum computing.
- The committee emphasizes that future investments in quantum computing facilities should complement -not displace- long-term research programs. As DOE advances toward a Quantum Computing User Facility, it will be essential to maintain a healthy balance between facility construction, operations, and sustained investments in fundamental research.
- Continued support for exploratory research will provide the innovation pipeline that drives future generations of capabilities and ensures that DOE User Facilities remain at the forefront of discovery.

The committee believes that the greatest legacy of the quantum initiative may extend well beyond the scientific challenges identified in this report. By pushing the boundaries of quantum science and technology, the Nation will create new knowledge, new technologies, and new industries that are impossible to fully predict today, just as previous generations of scientific infrastructure transformed computing, communications, medicine, and materials science.