U.S. DEPARTMENT of ENERGY | Office of Science

AUGUST, 2026

SCAC QUANTUM COMMITTEE **REPORT**

SCAC Quantum Subcommittee

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The Under Secretary for Science
Washington, DC 20585

April 1, 2026

Dr. Persis Drell
Chair
Office of Science Advisory Committee

Dear Dr. Drell:

Quantum technologies promise transformative advances in materials discovery, chemistry, communications, sensing, and computation and are of high importance across all programs and facilities of the United States (U.S.) Department of Energy's (DOE) Office of Science (SC) now and into the future. In particular, quantum computing is emerging as an important and practical application of foundational research in quantum technologies.

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. Further charges will follow the endorsement of the road map. As I anticipate 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.

Sincerely,

Darío Gil

Darío Gil
Under Secretary for Science

EXECUTIVE SUMMARY

Inflection point: Quantum computing is approaching a historic inflection point. Recent advances in logical qubits, quantum error correction, and system integration indicate that quantum computing is transitioning from R&D toward a scientifically revolutionary capability. For example, hybrid quantum-classical calculations have achieved chemically accurate simulations of protein-ligand systems containing more than 12,000 atoms, while quantum simulators have demonstrated real-time string breaking in lattice gauge theories, an important milestone toward first-principles simulations of fundamental particle interactions. Similarly, hybrid quantum-classical approaches are beginning to enable high-accuracy simulations of increasingly complex materials systems relevant to fusion energy, catalysis, and advanced manufacturing. Progress toward fault tolerance has accelerated substantially through advances in qubit performance, logical qubits, quantum error correction, and low-overhead coding schemes that significantly reduce the physical-qubit resources required for computation. These results suggest that the path toward fault-tolerant systems is becoming increasingly well defined. While scientific and engineering challenges remain, the Committee believes the coming decade presents a defining opportunity to establish quantum computing as a transformative scientific instrument that enables discoveries beyond the reach of conventional computing.

The charge: The Department of Energy Office of Science charged the SCAC Quantum Subcommittee with developing a roadmap to accelerate toward scientifically useful fault-tolerant quantum computing by 2028 and a long-term vision for a DOE Quantum Computing User Facility. To address this charge, the Committee engaged extensively with the quantum community through stakeholder interviews, a public Community Input Request, a community-wide Town Hall, and Committee deliberations with leaders from industry, academia, national laboratories, federal agencies, medicine, and international organizations. Despite the diversity of perspectives represented, a remarkable degree of consensus emerged regarding both the opportunities and the strategic direction for the Nation.

Transformative potential: Provided a set of definable scientific and technological challenges are met, quantum computing—empowered by the laws of quantum mechanics—has the potential to solve problems with long-ranging economic and societal impact that are unsolvable today or will take impracticably long to solve using today's classical computers. These include the exact prediction of molecular properties for revolutionary advances in drug discovery and biotechnology; transformative catalysts and industrial chemicals; secure communications guaranteed by the laws of physics; enormous speedups in the optimization of complex datasets such as are encountered in finance and supply chain management; practical fusion energy; and the understanding of neutron stars, stellar evolution, and the early Universe. These capabilities have the potential to accelerate breakthroughs across energy, medicine, advanced manufacturing, national security, and fundamental science while opening entirely new avenues of discovery that cannot yet be anticipated.

Why DOE? The Committee highlights that the Department of Energy is uniquely positioned to lead this next phase. Through sustained investments in the Office of Science core research programs, the National Quantum Information Science Research Centers, and partnerships spanning national laboratories, universities, and industry, DOE has established one of the world's leading quantum research ecosystems. DOE labs can now uniquely integrate quantum computing with leadership-class high-performance computing, artificial intelligence, scientific user facilities, advanced technologies and instrumentation, quantum sensing, networking, and multidisciplinary scientific expertise. This positions DOE not simply to deploy quantum computers, but to co-design and co-build future quantum systems with scientific users and technology experts, so that hardware, algorithms, software, AI, and experimental workflows evolve together around the Nation's most important scientific and technological challenges.

Why now? The Committee believes that the rapid maturation of multiple quantum computing platforms makes this the appropriate time to broaden the national effort by engaging a much larger scientific community in defining and solving ambitious scientific grand challenges on quantum computers. Continued advances in hardware, software, algorithms, systems engineering, and AI should proceed through continuous co-design with domain scientists, ensuring that scientific applications define technology requirements while technological advances continually expand scientific opportunity. At the same time, the Committee emphasizes that continued investment in foundational quantum technology research remains essential. The next phase should build upon DOE's successful long-term investments in quantum science and engineering -not replace them- while expanding the scientific communities that will ultimately drive discovery.

The recommended path

To accomplish this vision, the Committee recommends a phased strategy that progressively builds scientific capability while using clearly defined scientific and technical milestones to guide future investments, building upon successful quantum efforts at DOE and across the ecosystem. The roadmap is organized into three successive phases:

1. The Quantum Grand Challenges
2. The DOE Quantum Computing User Facility (QCUF)
3. Integration of Quantum Technologies Across the DOE Scientific Enterprise

A first phase and foundational component of the recommended strategy is to establish **DOE Quantum Grand Challenges** that incentivize multidisciplinary teams from national laboratories, universities, and industry to advance toward milestone-driven goals. The challenges should encompass scientific applications, hardware technologies and prototypes, algorithms, software, coupling to classical high-performance computing (HPC) and AI, systems scaling and engineering, as objective scientific and technical milestones. Industry should be encouraged to compete across multiple hardware modalities while collaborating with scientific users through both existing and new partnership models that accelerate co-design. In addition, the DOE should consider providing early access to available, or soon-to-be-realized, quantum computers for developing and testing grand challenge ideas.

This phase of the roadmap is designed to address the Committee's charged objective of demonstrating a scientifically relevant, error-corrected quantum computing capability by 2028. Rather than focusing on hardware metrics alone, the Quantum Grand Challenges combine milestone-driven technology development with ambitious scientific challenge problems so that progress is measured by both advances in fault-tolerant quantum computing and the ability to solve increasingly important scientific problems.

The Quantum Grand Challenges will be a practical vehicle to bring focus, to advance and measure technical maturity, community readiness, and user base needed to lay the foundation and inform the specifications of a DOE **Quantum Computing User Facility (QCUF)**. An ambitious user facility would represent the culminating point in advancing quantum computing for scientific discovery. As with DOE's other world-leading user facilities, its goal will be enabling open, transparent, merit-based exploration of applications for various user communities. Rather than being built around a single institution or technology provider, the Committee envisions the QCUF as a national enterprise that harnesses the complementary strengths of DOE labs, universities, industry and the broader research community through continuous co-design.

Looking beyond, the Committee envisions a longer-term phase in which quantum computing becomes an integrated and foundational capability within the DOE scientific ecosystem. As different quantum technologies continue to mature and scientific opportunities expand, quantum computing systems of different scale and capabilities should be integrated with leadership-class HPC, AI, networking, scientific user facilities, experimental platforms, and quantum sensors to enable new modes of scientific discovery. The Committee does not envision predetermined architectures or technology pathways. Rather, future investments should be guided by demonstrated scientific utility, technical maturity, community demand, and continued rigorous evaluation, while preserving healthy competition across multiple approaches.

The effort to realize this vision creates an unprecedented opportunity to mobilize the Nation's scientific ecosystem in a manner reminiscent of other transformative national initiatives: bringing together DOE laboratories, universities, industry, several federal agencies, and international partners, each contributing their unique scientific expertise, technologies, facilities, and capabilities toward a shared national goal.

The Committee envisions this as an evidence-based progression that brings focus, demonstrates scientific value, technical readiness, and community demand.

The Committee therefore makes six principal recommendations:

1. Build upon DOE's Leadership in Quantum Information Science Through a Phased Quantum Computing Initiative that includes pioneering a DOE fault-tolerant quantum computing facility for users.
2. Establish DOE Quantum Grand Challenges competitions that incentivize multidisciplinary teams to achieve milestone-based demonstrations of hardware progress, prototypes and scientific utility.
3. Develop new partnership models that deepen collaboration among national laboratories, universities, and industry through sustained co-design while lowering barriers to scientific collaboration and preserving appropriate intellectual property protections.
4. Strengthen quantum computing as an integral component of the DOE Office of Science research enterprise by integrating it with the core domain science research and technology programs, leadership-class HPC, artificial intelligence, scientific user facilities, quantum sensing and networking, driving open standards for diversity of quantum-classical hybrid compute solutions.
5. Broaden investments across the quantum technology stack and build upon DOE's internationally recognized strengths in superconductivity, cryogenics, advanced material science and engineering, accelerator science, microelectronics, scientific instrumentation, and large-scale systems engineering.
6. Sustain national investments commensurate with the opportunity while maintaining a healthy balance between long-term research and future scientific infrastructure. Continued investments in fundamental quantum science, enabling technologies, and applications will remain essential to ensuring that future user facilities continue to evolve and maintain scientific leadership.

The Committee finds that the recently announced **Quantum Genesis Initiative** is strongly aligned with this vision. The proposed DOE Q Competition, focused investments in quantum computing applications, and the National Quantum Supercomputing User Facility naturally map onto the phased roadmap presented in this report. The Committee believes this roadmap provides an overarching scientific framework that connects these initiatives into a coherent long-term national strategy centered on scientific utility, multidisciplinary co-design, and milestone-driven progress.

The Committee believes that the greatest legacy of this initiative may extend well beyond the scientific challenges identified in this report. By pushing the boundaries of quantum science and engineering, the Nation will create new knowledge, new technologies, and new industries whose full impact cannot yet be anticipated, just as previous generations of scientific infrastructure transformed computing, communications, medicine, and materials science. The investments recommended in this report will not simply build quantum computers—they will establish a new national capability for scientific discovery, strengthen U.S. scientific leadership, drive economic competitiveness and enhance national security.

COMMITTEE PROCESS & APPROACH

The DOE Office of Science charged the SCAC Quantum Committee with developing a roadmap to accelerate scientific discovery through quantum computing while strengthening U.S. leadership in quantum information science. As the Committee interpreted this charge, it became clear that the requested roadmap should address two complementary objectives: (1) define the critical milestones required between now and 2028 to demonstrate meaningful scientific utility using error-corrected quantum computing, and (2) articulate a longer-term vision for a DOE Quantum Computing User Facility capable of serving the Office of Science over the following decade.

To ensure that the roadmap reflected the perspectives of the broader quantum ecosystem, the Committee adopted an extensive community engagement strategy. This included structured interviews with leaders from industry, academia, national laboratories, federal agencies, and international organizations; a public Community Input Request; a one-day virtual Community Town Hall; and multiple Committee deliberations. Collectively, these activities engaged hundreds of participants representing quantum hardware developers, software and algorithm researchers, computational scientists, domain scientists, technology strategists, and future user communities, both national and international.

Throughout this process, the Committee sought not to identify a single technological pathway, but rather to understand where broad consensus exists, where uncertainties remain, and what scientific and technical milestones should guide future DOE investments. The roadmap presented in this report reflects the synthesis of these diverse perspectives together with the Committee's independent deliberations.

SCAC Quantum Subcommittee: Timeline & Community Engagement

Extensive 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

This report reflects extensive engagement across the quantum ecosystem.

The roadmap and recommendations are grounded in a diverse set of perspectives and a shared commitment to advancing scientific discovery with quantum computing.

40 interviews | **>100** CIR submissions | **400+** town hall participants

STATE OF THE ART

The Committee's conclusion that quantum computing has reached an inflection point is grounded in the convergence of significant advances across the full quantum computing stack. Recent years have seen rapid progress not only in hardware performance, but also in fault-tolerant architectures, quantum algorithms, software, error correction, systems engineering, and increasingly compelling scientific applications. Importantly, these advances are no longer occurring in isolation. They are beginning to reinforce one another, enabling increasingly sophisticated demonstrations that collectively move the field from technology development toward scientific utility.

Recent scientific achievements illustrate this transition. Hybrid quantum-classical workflows have extended first-principles quantum chemistry calculations to protein-ligand systems containing more than 12,000 atoms and enabled chemically accurate simulations of industrially relevant materials, including molten salts for fusion energy and catalytic metal-organic systems. At the same time, quantum simulators have reproduced the dynamics of two-dimensional lattice gauge theories, including real-time string breaking, while quantum computers have been used to accurately reconstruct the magnetic excitations of correlated materials by benchmarking directly against neutron-scattering experiments. These examples demonstrate that quantum computers are increasingly being used not simply to benchmark themselves, but to address scientifically meaningful problems while becoming directly integrated with experimental science, scientific instruments, and existing DOE user facilities.

Advances in fault tolerance are equally significant. New quantum error-correction schemes have demonstrated substantially lower overhead, while multiple hardware platforms have crossed important experimental milestones, including logical qubits operating below error-correction thresholds, reconfigurable neutral-atom architectures with hundreds of atoms, and programmable trapped-ion systems capable of implementing multiple error-correcting codes on a single device. At the same time, progress in verification and sampling has begun to establish the trust and reproducibility required for scientific computing.

Equally important, substantial progress has been made in the enabling technologies required for scalable systems. Improvements in superconducting qubits coherence times, ultra-coherent cavity-based qudits, reconfigurable atom arrays, silicon spin qubits, quantum networking concepts, cryogenic engineering, and integration with leadership-class high-performance computing demonstrate that many of the critical components of future fault-tolerant systems are advancing simultaneously across multiple hardware modalities. Through close partnerships with industry, the DOE National Quantum Information Science Research Centers are already serving as hubs to co-design, validate, and mature these technologies while reducing technical risk.

Taken together, these developments suggest that the field is entering a new phase. The Committee believes the question is no longer simply whether fault-tolerant quantum computing is scientifically feasible, but **how to organize the Nation's research ecosystem to accelerate its transition into a transformative scientific instrument.** This convergence of scientific applications, enabling technologies, and system-level capabilities creates a timely opportunity for DOE to broaden participation, define ambitious scientific milestones, and establish a coordinated roadmap toward scientifically useful quantum computing.

FINDINGS

The Committee found a remarkable degree of convergence across stakeholder interviews, written community input, and the Community Town Hall. Although participants represented diverse institutions, hardware platforms, scientific disciplines, and organizational perspectives, several consistent themes emerged, forming the foundation of this report.

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.

Just as previous generations of scientific infrastructure enabled transformative advances across science and technology, fault-tolerant quantum computing has the potential to revolutionize our ability to understand and engineer nature. It could enable breakthroughs in chemistry, materials, biology, fusion energy, particle and nuclear physics, national security, and other areas of societal impact, while opening entirely new avenues of scientific inquiry that cannot yet be anticipated.

The Committee believes the United States is at a pivotal moment. Strategic investments made during the next several years will determine whether the Nation leads the development of quantum computing as a foundational capability for scientific discovery throughout the twenty-first century.

Finding 2: Scientific utility has become a central 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 the development of meaningful applications, guide technology development, and build the broad user communities needed for future quantum computing capabilities.

Finding 3: DOE is uniquely positioned to lead the next phase of scientific quantum computing.

Over the past decade, DOE has established one of the world's leading quantum research ecosystems through sustained investments in Office of Science programs, the National Quantum Information Science Research Centers, and partnerships spanning national laboratories, universities, industry, and international collaborators.

A recurring theme throughout the Committee's engagement was that DOE has the opportunity to 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.

Rather than simply deploying commercial quantum computers and identifying subsequent applications, DOE has the opportunity to co-design future quantum computing systems alongside scientific users, tailoring hardware, algorithms, software, and experimental workflows to address specific scientific grand challenges. This approach mirrors the successful development of DOE accelerators, light sources, neutron facilities, and large-scale detectors, where scientific objectives have historically driven instrument design.

DOE can develop quantum computing as a scientific capability that complements and extends commercial efforts.

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 remains critical. Achieving scalable, 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.

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. Realizing the full promise of quantum computing will require sustained national commitment, continued public-private collaboration, and investments commensurate with the scale of the scientific opportunity.

As with previous landmark scientific initiatives, the ultimate impact of quantum computing is likely to extend well beyond today's envisioned applications, creating new knowledge, transformative technologies, and future industries that cannot yet be fully anticipated.

A THREE-DIMENSIONAL 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. 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, measuring progress, and informing future decisions. The Committee emphasizes that these roadmaps are not intended to represent an exhaustive inventory of all potential scientific applications, hardware performance metrics, or enabling technologies. Rather, they should be viewed as a practical starting point for organizing DOE investments and establishing measurable milestones across a rapidly evolving landscape. The Committee encourages DOE to periodically revisit and expand these roadmaps through community workshops, broad stakeholder engagement, scientific campaigns, and regular reassessment of emerging opportunities, ensuring that they continue to reflect advances in both science and technology.

Science Roadmap

The Committee envisions that a central element of DOE's quantum computing strategy should be a **science-driven roadmap**, in which increasingly ambitious scientific grand challenges define the requirements for advances in quantum computing. The roadmap emphasizes the progressive demonstration of **scientific utility**—the ability of fault-tolerant quantum systems to answer important scientific questions that remain beyond the reach of conventional computational approaches. Advances in algorithms, hardware, software, artificial intelligence, systems engineering, and quantum architectures should therefore be guided through continuous co-design with the scientific communities that will ultimately use these capabilities.

The scientific challenges identified in this roadmap illustrate opportunities where quantum computing could transform discovery across the DOE mission while simultaneously addressing broader national priorities. Early demonstrations are already showing that quantum computers can contribute to chemically accurate simulations of large molecular systems, predict the properties of fusion-relevant materials, reproduce the behavior of correlated quantum materials, simulate fundamental particle interactions, and operate in direct conjunction with experimental platforms such as neutron-scattering instruments and quantum sensors.

The Committee identified a set of measurable milestones that could establish **scientific utility by 2028**. These include accurately predicting the electronic structure of catalytically important molecules; modeling the behavior of strongly correlated materials relevant to superconductivity and advanced manufacturing; delivering validated simulations of fusion-relevant materials and plasma processes; performing realistic simulations of neutrino and nuclear interactions; and reproducing key phenomena in quantum field theories governing particle physics.

Looking toward the **2030s**, the Committee envisions quantum computing enabling transformational scientific breakthroughs, including the first-principles design of new medicines and therapeutic proteins; the discovery of revolutionary catalysts for clean chemical manufacturing; the development of next-generation superconductors, batteries, and quantum materials; predictive simulations that accelerate the deployment of practical fusion energy; precise calculations of nuclei, quarks, gluons, and neutrino interactions; and simulations of the extreme conditions that governed the formation and evolution of the Universe.

Collectively, these grand challenges address some of the most fundamental scientific questions facing the Nation while advancing critical priorities in energy security, biotechnology, advanced manufacturing, microelectronics, national security, and U.S. scientific leadership. As with previous generations of transformative scientific infrastructure, the Committee believes that pushing the boundaries of quantum science will not only accelerate discovery but will also enable entirely new technologies and industries that cannot yet be fully anticipated.

The Committee recommends a staged progression between 2026 and 2028 in which multidisciplinary teams pursue increasingly sophisticated scientific demonstrations. Industry providers of quantum computing capabilities could also compete toward demonstrating hardware milestones.

Initial milestones should focus on benchmark problems that establish the correctness and reliability of fault-tolerant quantum computation through rigorous validation against classical methods or experiment. Intermediate milestones should extend these capabilities to scientifically relevant systems that push beyond current computational limits. By 2028, the objective is to demonstrate the first **scientifically relevant quantum applications** that provide new predictive capability or scientific insight on strategically important problems, or efficiency advantages, establishing clear evidence that quantum computing can become a transformative scientific instrument.

Beyond 2028, these demonstrations may naturally evolve into large-scale scientific campaigns supported by several instruments under one DOE National Quantum Computing User Facility, if justified by demonstrated scientific utility, technical maturity, and community readiness. Over the longer term, quantum computing and related quantum technologies should become progressively integrated throughout the DOE scientific enterprise.

Importantly, the Committee does not view this roadmap as prescribing a single technological pathway. Different quantum computing architectures will likely advance at different rates and prove advantageous for different scientific applications. The roadmap is therefore intentionally **technology-agnostic**, encouraging competition across multiple hardware modalities while evaluating progress through common scientific and technical milestones centered on scientific impact. In addition to supporting multiple modalities, driving open interconnect standards will enable innovation of classical-quantum hybrid computing and networking solutions. In this vision, **scientific grand challenges define the requirements, advances in quantum technology provide the enabling capability, and success is ultimately measured by transformative scientific discovery.**

SCAC Roadmap: Path to an Integrated Quantum Future

GRAND SCIENTIFIC CHALLENGE	2026 FOUNDATIONAL DEMONSTRATIONS	2027 SCALING LARGER
DESIGNING NEW MEDICINES & BIOLOGICAL TOOLS	Calculate few active sites, molecular fragments, and photoactive molecules	Simulate excited states and protein–ligand interactions
TRANSFORMING CHEMICAL MANUFACTURING & CATALYSIS	Calculate strongly correlated bonds and small catalytic centers on clusters	Simulate steps in catalytic reactions on transition metals and metalloenzymes
DISCOVERING NEXT-GENERATION MATERIALS & SUPERCONDUCTORS	Simulate simple materials models that reproduce experiments	Extend to more complex models relevant to correlated materials
ENABLING PRACTICAL FUSION ENERGY	Calculate tritium binding, simple plasma-response models, or transport in materials	Calculate rates, conductivities, and tritium behavior in candidate materials
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
REPLAYING THE BIG BANG	Simulate simplified models of dynamics of dense quark and gluon matter	Simulate particle-spray formation and quark-matter flow.
SENSING THE UNDETECTABLE	Read out a quantum sensor with qubits, beating the best classical readout scheme.	Entangle sensor arrays with error-corrected readout, using exponentially fewer measurement resources.

SCAC ROADMAP PHASES

PHASE 1: QUANTUM CHALLENGES (2026-2028)

Build and scale capabilities through milestone-driven challenges across priority scientific domains

GUIDED BY EVIDENCE — Decisions based on scientific utility and rigorous evaluation

MILESTONE-BASED — Clear targets to measure progress and inform investments

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

2028 SCIENTIFIC-RELEVANT DEMO (Transition)	2030+ LONG-TERM BREAKTHROUGH	IMPACT WHY IT MATTERS (Scientific & Societal)
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
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
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
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
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
Deliver first phenomenological inputs to event generators.	Predict collider inputs from first principles and the dynamics of the early-universe plasma	• Discover the fundamental laws of nature • Extending reach of LHC, EIC, and exploration of the early universe
Extend sensing past the coherence limit, with a published sensitivity gain on a scientific measurement.	Entangle sensors with a fault-tolerant processor, benchmarked across platforms on a common standard	• Single-molecule spectroscopy, nanoscale materials imaging, rare-event searches beyond classical detector reach, GPS-free navigation

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.

COMMUNITY-INFORMED — Broad engagement to drive innovation, access, and inclusion

CONTINUOUSLY REASSESSED & EVOLVING — Annual review ensures flexibility and responsiveness to scientific and technological advances

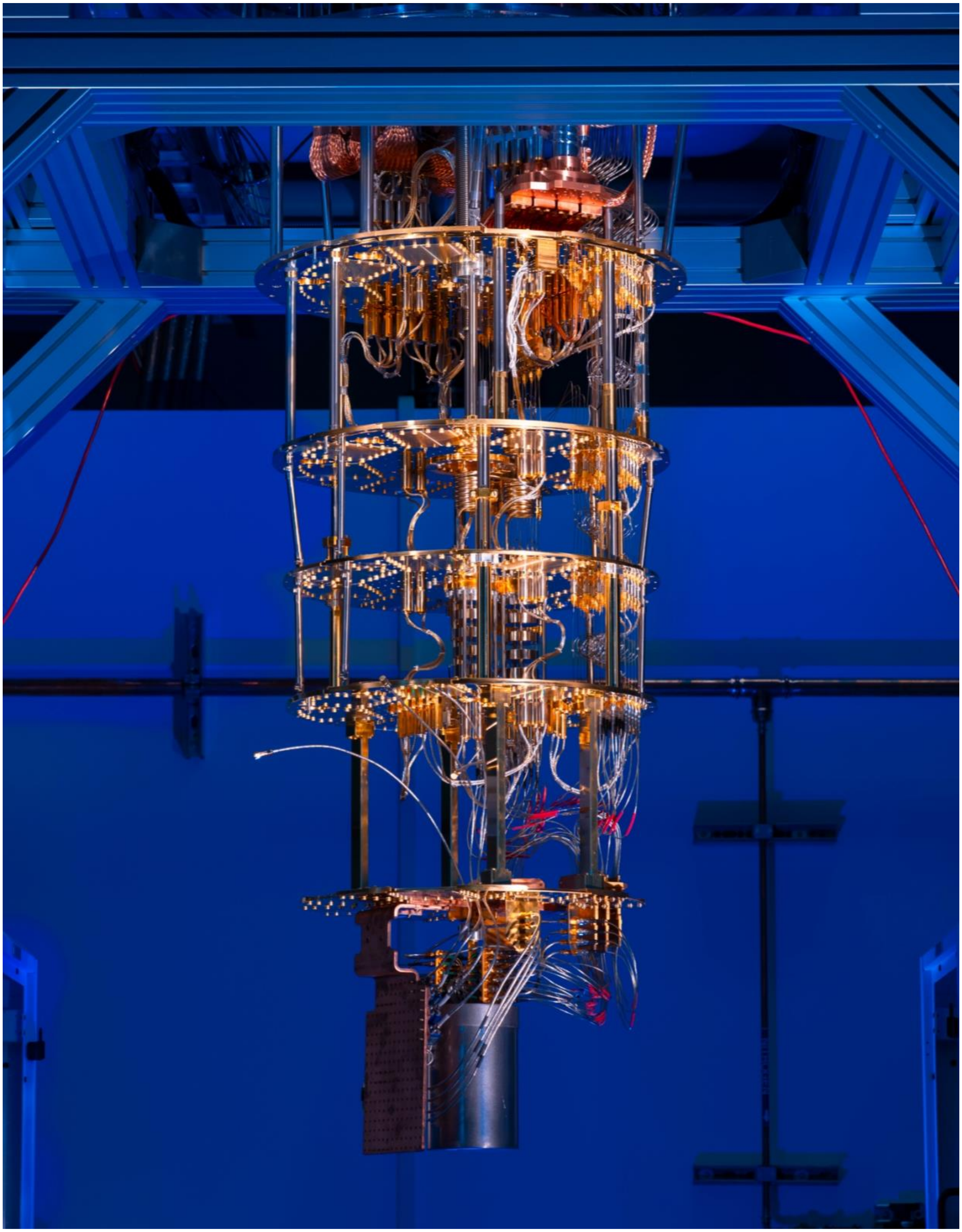

Photo Credit: Ryan Postel, Fermilab

Hardware Capability Roadmap

Complementing the scientific roadmap, the Committee recommends a hardware capability roadmap that establishes progressively more demanding system-level milestones for fault-tolerant quantum computing while remaining technology neutral.

Rather than prescribing specific hardware implementations, the roadmap defines illustrative performance ranges—including logical qubit count, logical operations, accuracy and reliability, speed and connectivity, system integration, and scientific validation—that **collectively** indicate increasing scientific capability. The objective is not simply to maximize hardware performance but to demonstrate systems capable of supporting increasingly complex scientific workflows.

By 2028, the Committee envisions hardware capable of executing the first scientifically relevant fault-tolerant applications with demonstrated predictive value. Looking beyond 2028, continued advances toward approximately 1,000 logical qubits and sustained fault-tolerant operation will enable a user facility supporting transformational scientific campaigns across multiple DOE mission areas.

Quantum System Hardware Capability Progression

(Illustrative Ranges Across Platforms)

	2026 VERIFIED DEMONSTRATIONS	**2027** SCALABLE SYSTEMS
LOGICAL QUBITS	~1 – 10 logical qubits	~10 – 50 logical qubits
HARD LOGICAL OPERATIONS	Up to ~10^4 quantum operations in tightly controlled demonstrations	~10^3 – 10^4 hard logical operations
SPEED & TIME TO RESULT	~10 – 10^4 logical operations per second; much of the time spent resetting rather than computing	~10× more logical operations per hour at the same accuracy
CONNECTIVITY BETWEEN QUBITS	Effective connectivity: linking distant qubits costs ~2 – 10× more time and error than neighbors; ~1× on small fully connected machines	Effective connectivity improved ~3× on machines of ~100+ qubits
ACCURACY & RELIABILITY	Logical operations demonstrated and classically benchmarked	Lower logical error rates; repeatable multi-logical-qubit workflows
SYSTEM INTEGRATION	Early logical-qubit demonstrations	Integrated control, decoding, software, and calibration
SCIENTIFIC VALIDATION	Direct classical verification	Classical verification or high-quality emulation where feasible

2028 SCIENTIFIC-RELEVANT DEMONSTRATIONS	2030+ USER FACILITY CAPABILITY
~50 – 100+ logical qubits	~1,000 – 10,000 logical qubits for transformative campaigns
~10^4 – 10^5 hard logical operations	~10^9 – 10^{10} hard logical operations for large scientific applications
A full scientific calculation returned within 24 hours	~10^9 – 10^{10} operation campaigns finished in days, computing >80% of the time
Effective connectivity within ~2× of ideal across a ~1,000-qubit machine	Within ~1.5× of ideal across ~10^6 – 10^7 qubits; linked modules behave as one machine
Reliable fault-tolerant execution sufficient for end-to-end scientific calculation	Production-level reliability for sustained scientific campaigns
End-to-end quantum–HPC–AI workflow with scientific validation	Results beyond routine classical reach, integrated with experiments and DOE user facilities
Independent validation against experiment, classical limits, or predictive scientific value	Results beyond routine classical reach, integrated with experiments and DOE user facilities

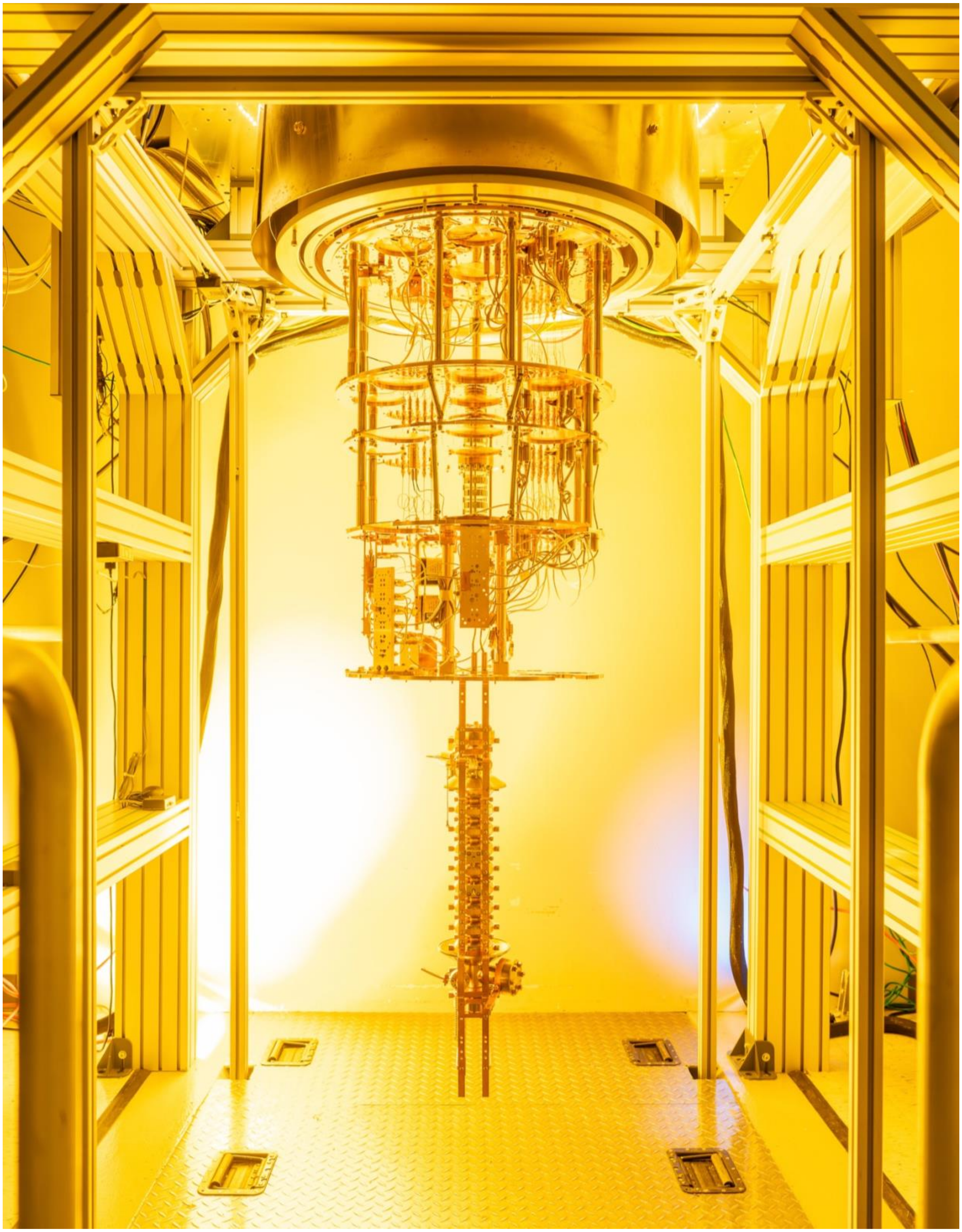

Photo Credit: Ryan Postel, Fermilab

Technology Roadmap

In parallel with the scientific and hardware roadmaps, the Committee recommends a third roadmap focused on the enabling technologies and systems demonstrations required to progress from early fault-tolerant prototypes to a user-ready system at the scale of roughly 1,000 logical qubits and beyond.

This roadmap should address the principal bottlenecks across the full technology stack: extending coherence and reducing physical and logical error rates; demonstrating scalable error-correction protocols and real-time decoding; integrating control electronics, cryogenics, cabling, and packaging at increasing system scale; validating modular and heterogeneous architectures and quantum interconnects; establishing reliable software, compilers, verification, calibration, and automated operations; and demonstrating manufacturability, reproducibility, uptime, and maintainability.

Early milestones should validate these capabilities on small, logical systems; intermediate milestones should show that they scale without unacceptable losses in fidelity, speed, or reliability; and later demonstrations should integrate the complete stack in sustained, end-to-end scientific workflows. Progress toward a 100- and ultimately 1,000-logical-qubit capability should therefore be assessed not only by logical-qubit count, but by whether the system can operate reliably, repeatedly, and at sufficient throughput to support demanding scientific campaigns, and the scalability potential.

Technology Demonstration Roadmap

	2026	2027
QUBIT & QUDIT QUALITY COHERENCE, LOSS & FIDELITY	Hold a two-qubit error $\leq 10^{-3}$ system-wide	Improve on that error rate while operating a full processor
ERROR CORRECTION & LOGICAL QUBITS	Show all error types fall exponentially as the code grows, with ≥6× suppression	Run a scientific algorithm end to end on logical qubits, beating the same algorithm run without error correction
CONTROL & READOUT SYSTEMS	Fix errors in real time while the computation runs, on ≥100 physical qubits	Run an order of magnitude more qubits from one control system, with no error penalty
ENABLING INFRASTRUCTURE & SYSTEM INTEGRATION	Specify per-qubit cooling, wiring, power and footprint at today's largest system	Show heat, vibration and EM/optical noise keep the machine inside speced error budget
MODULAR ARCHITECTURES & CONNECTIVITY	Entangle two separately built modules at >99% fidelity, ≤10× the local gate time	Interconnecting two full processors at the current largest scale, without degrading the coherence
SOFTWARE, COMPILERS & ALGORITHMIC TOOLS	Predict an algorithm's qubit count and runtime in advance, then land within 2× of measurement	An outside team runs a standard error-corrected benchmark using only the public toolchain
MANUFACTURING & SUPPLY CHAIN	≥50% of designed qubit capacity meets a pre-published spec as built, across three consecutive batches, none discarded	Raise as-built yield substantially across multiple consecutive batches
RELIABILITY, DIAGNOSTICS & OPERATIONS	24 hours of error-corrected running with scheduled calibration only, logical error stable within 2×	Run for weeks unattended while continuously error-correcting

2028 GOAL

Demonstrate an integrated, reliable, and scalable technology stack on a credible path to a ≥1,000-logical-qubit user facility.

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.

2028	2030+	OUTCOME
Hold the improved error rate at an order of magnitude larger scale, with nearly all qubits live simultaneously	**MOONSHOT:** Error rates well below today's best, held across a facility-scale processor	High-fidelity qubits with error rates low enough for large-scale error correction
Reach logical error rates of a part per million of physical error rates, with correction applied in real time	**MOONSHOT:** A scientific campaign that runs to completion on a facility-scale logical processor	Validated error correction that suppresses errors exponentially with scale
Measurement during the calculation, on every qubit, accurate enough not to limit the correction loop	**MOONSHOT:** A facility-scale machine decoded in real time within a practical power envelope	Scalable, low-latency control and readout enabling fault-tolerant operation
Run the full supporting infrastructure at half the power per qubit of the entire system	**MOONSHOT:** A scheduled national user facility running at high availability on practical power	Infrastructure capable of reliably supporting large-scale quantum systems
Perform logical operations across a module boundary at system scale, achieving swappable modular architecture with error correction without disassembling the system	**MOONSHOT:** A facility of field-replaceable modules where the seam is no longer a distinguished error or speed channel	Modular, connected, and serviceable architectures enabling scalable systems
One unmodified program runs on more than one hardware platform, with cost and accuracy predicted in advance	**MOONSHOT:** One open toolchain runs a facility-scale scientific campaign, predicted accurately before switch-on	Software stack ready for fault-tolerant quantum applications at scale
Establish measured cost per qubit at scale, with a qualified second source for critical components	**MOONSHOT:** A domestic industrial base able to deliver and periodically upgrade a national facility	Manufacturable, reliable, and cost-effective supply chain for scaling
A months-long campaign at high availability on an error-corrected system	**MOONSHOT:** Years of hands-off operation, absorbing component failures without losing the calculation	Reliable, maintainable systems ready for facility operations

Note: Milestones are architecture-agnostic. Platforms report progress in their native primitives (e.g., two-qubit gate, transversal gate, fusion operation) and are compared through common, independently reproducible benchmarks rather than a single hardware metric.

DEFINING CONSIDERATIONS FOR A DOE QUANTUM COMPUTING USER FACILITY

The Committee envisions a **DOE Quantum Computing User Facility** as a long-term national endeavor that will establish quantum computing as a foundational capability for scientific discovery across the Office of Science. Rather than simply constructing a facility, DOE should ensure that researchers from national laboratories, universities, industry, and federal agencies co-develop the next generation of quantum-enabled scientific instruments.

Unlike existing models that primarily deploy commercial quantum computers within research institutions, the Committee believes DOE can distinguish itself by applying the same philosophy that has guided its most successful scientific facilities: **science drives instrument design**.

Accordingly, the Committee envisions future quantum computing systems being co-designed alongside domain scientists pursuing grand scientific challenges. Hardware, algorithms, software, AI, and experimental workflows should evolve together to maximize scientific impact, rather than optimizing individual technology components in isolation.

Scientific Impact

The ultimate purpose of a DOE Quantum Computing User Facility is not simply to maximize quantum hardware performance, but to maximize scientific discovery. The Committee envisions the facility as a scientific instrument enabling transformative advances across chemistry, biology, materials science, condensed matter physics, particle and nuclear physics, fusion energy sciences, optimization, and other emerging disciplines.

As with DOE's other world-leading user facilities, these scientific breakthroughs will ultimately drive broad societal and industrial impact by enabling new technologies, strengthening U.S. competitiveness, and fostering innovation as quantum technologies mature and the **user community expands.** Increasingly, quantum computing should also operate alongside quantum sensing and quantum-enabled experiments, enabling entirely new classes of hybrid scientific workflows in which computation and experiment evolve together. Scientific applications should therefore become the primary driver for hardware evolution, software development, algorithms, systems engineering, and facility design.

Scientific Communities

The Committee consistently heard that the future success of quantum computing depends upon broadening the community beyond quantum information scientists themselves. The envisioned facilities should serve researchers across the Office of Science and beyond, while fostering sustained collaboration among quantum hardware developers, software and algorithm researchers, computational scientists, AI experts, and domain scientists.

Several stakeholders emphasized that the greatest acceleration occurs by both: **deploying quantum hardware into laboratories**, and **by bringing multidisciplinary teams together over extended periods to jointly develop scientific applications.** Examples discussed during the Committee's engagement - including exemplar collaborations between QuEra and Los Alamos National Laboratory and between IBM and Cleveland Clinic, or IBM and RPI - illustrate the benefits of embedding hardware and hardware developers directly alongside scientific users. **The**

Committee believes this hardware and people-centered model of co-design should become a defining characteristic of future DOE quantum facilities.

DOE's Unique Role

The Committee believes DOE occupies a unique position within the national quantum ecosystem. Industry is driving remarkable innovation in quantum hardware and software. Universities continue to provide pioneering research and workforce development. DOE National Laboratories bring complementary strengths that are difficult to replicate elsewhere, including multidisciplinary scientific expertise, large-scale engineering, advanced user facilities, high-performance computing, AI infrastructure, networking, and long-term programmatic continuity. Accordingly, the Committee envisions DOE acting not as a competitor to industry, but as the national integrator that brings together technologies, scientific users, and multidisciplinary teams to create large-scale, unique capabilities that neither government nor industry could realize independently.

A Portfolio of Instruments Rather than a Single Winner

One of the strongest messages emerging from the Committee's engagement is that the field remains sufficiently dynamic that **no single hardware modality should be selected prematurely as the sole national approach.**

The Committee envisions a potential future **portfolio of complementary instruments**, each advancing distinct 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 and cavities, neutral atoms, trapped ions, photonics, spin qubits, and future emerging technologies);
- different architectural concepts (modular systems, heterogeneous quantum-HPC integration, hybrid quantum systems, qudits, 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.

Rather than viewing these efforts as competing, the Committee envisions them as complementary components of a national quantum ecosystem that collectively maximize scientific impact while preserving technological diversity.

Hybrid deployment model (cloud vs on-prem)

The Committee believes that a future user facility should combine multiple modes of access. Cloud-based access will continue to play an important role by providing broad availability, rapid experimentation, and connections to commercially developed hardware. At the same time, co-located systems at DOE National Laboratories offer unique opportunities that cannot readily be replicated remotely. These include:

- close interaction between hardware developers and scientific users;
- integration with leadership-class HPC systems and AI infrastructure and expertise;
- coupling with scientific instruments and experimental facilities;
- use and development of advanced cryogenic, interconnects/networking capabilities;

- rapid hardware-software co-design;
- scaling and interconnect prototyping;
- workforce development through embedded multidisciplinary teams.

The Committee therefore anticipates a hybrid model in which cloud and on-premises resources complement one another, each serving distinct but mutually reinforcing roles.

User Program

The Committee envisions the Quantum Computing User Facility operating as a true DOE scientific user facility, with peer-reviewed access and resident scientific expertise that enables users to fully leverage the facility's capabilities.

The user program should support multidisciplinary research teams, scientific user support, workforce development, and community engagement through collaborative software, benchmarking activities, training, and scientific workshops. As with other DOE user facilities, the Committee believes that a vibrant and diverse user community will be essential to maximizing the facility's scientific impact and ensuring its continued evolution.

Planning the Path Toward a Quantum Computing User Facility

The Committee recognizes that determining the appropriate timing, scale, and scope of a DOE Quantum Computing User Facility requires 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 NQISRCs, national laboratories, universities, industry, and the prospective user community.

Among the questions DOE should address with such activity 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. Unlike a stand-alone hardware acquisition, a DOE Quantum Computing

User Facility would integrate quantum hardware with scientific instrumentation, cryogenic systems, networking, high-performance computing, systems integration, operations, user support, and the scientific and engineering workforce required to develop and operate the facility. The Committee therefore recommends that future cost estimates be developed through a rigorous, community-informed process involving DOE laboratories, the National Quantum Information Science Research Centers, academia, industry, and the formal DOE project management process.

TOWARD AN INTEGRATED QUANTUM FUTURE

The Committee does not envision a single predetermined facility architecture or technology pathway. Rather, it recommends an evolutionary, milestone-driven approach in which scientific utility, technical maturity, and community demand guide future investments. As quantum technologies continue to advance, prototype systems, technology demonstrators, and mission-driven user facilities should evolve only as justified through rigorous evaluation and demonstrated scientific impact.

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.**

As quantum technologies mature, these capabilities should be deployed wherever they provide the greatest scientific value, complementing leadership-class HPC, artificial intelligence, advanced networking, scientific user facilities, accelerators, light sources, neutron sources, fusion experiments, and other Office of Science facilities. Rather than existing as isolated resources, quantum capabilities should become integrated components of scientific workflows, enabling new modes of computation, sensing, simulation, control, and data analysis across the DOE research portfolio.

The Committee does not recommend committing today to specific long-term facility configurations or technology pathways. Instead, future investments should continue to be guided by demonstrated scientific value, technical readiness, community needs, and rigorous peer review while preserving healthy competition across multiple hardware approaches and maintaining flexibility as the field evolves.

In the long term, the Committee envisions quantum technologies becoming a foundational scientific capability of the DOE research enterprise. Just as leadership-class computing, advanced detectors, accelerators, and light sources are now indispensable tools for discovery, quantum computing and related quantum technologies should progressively become integrated across DOE's portfolio of scientific facilities and experiments, expanding the scientific reach of the Office of Science while enabling discoveries that cannot be achieved by conventional approaches alone.

RECOMMENDATIONS

Recommendation 1: Build upon DOE's Leadership in Quantum Information Science Through a Phased Quantum Computing Initiative that includes pioneering a DOE Fault-Tolerant Quantum Computing Facility for users.

The Committee commends DOE for establishing one of the world's leading quantum research ecosystems through sustained investments in fundamental science, the Office of Science core research programs, the National Quantum Information Science Research Centers, and strong partnerships with universities and industry. Building on this foundation and aligning with Quantum Genesis's goals, 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

The initiative should begin with **Quantum Grand Challenges** that incentivize multidisciplinary teams to achieve ambitious milestones. Through milestone-driven competition, this phase should simultaneously advance scientific applications, quantum hardware, prototypes, algorithms, software, and systems engineering, while broadening the scientific user community and preserving healthy competition across multiple hardware approaches.

Phase II – DOE Quantum Computing User Facility

The Quantum Grand Challenges Phase will accelerate the establishment of the scientific applications, technology readiness, user community, and operational concepts needed to inform and optimize the implementation of a **DOE Quantum Computing User Facility (QCUF)**. As envisioned in Quantum Genesis, the Committee believes that a mission-driven QCUF represents a critical next step toward broad scientific access to fault-tolerant quantum computing for DOE communities and for the Nation. As with DOE's other world-leading user facilities, its success should ultimately be measured by the scientific discoveries it enables.

The Committee 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.

Phase III – Integration Across the DOE Scientific Enterprise

Looking beyond the QCUF, the Committee envisions a future in which quantum computing and related quantum technologies are increasingly integrated across the DOE scientific enterprise. As technologies mature, quantum capabilities of different scales and modalities should be deployed wherever they provide the greatest scientific value—complementing leadership-class HPC, artificial intelligence, scientific user facilities, experimental platforms, quantum sensing, and advanced networking. The Committee does not envision predetermined facility architectures or technology pathways. Rather, this long-term evolution should remain technology-neutral and be guided by demonstrated scientific utility, technical maturity, community priorities, and rigorous evaluation.

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, focused quantum **grand challenge competitions**, to accelerate the path toward demonstrating a scientifically relevant, error-corrected quantum computing capability by 2028. During this phase, DOE should leverage its major quantum initiatives to the fullest.

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. Some of these novel partnership models are discussed in recommendation 3. As outlined in the SCAC roadmap, scientific **grand challenges** should define the requirements that drive technology development rather than simply adapting applications to existing hardware.

The Committee recommends assessing the viability of multiple scientific use cases, of hardware modalities and technology demonstrations throughout the challenge period. Merit-based evaluation against common scientific and technical milestones should inform the design, architecture, and use cases for a future QCUF while preserving flexibility as technologies continue to mature.

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. By engaging the broader research community in ambitious multidisciplinary teams, this phase can stimulate innovation, attract new talent, strengthen **public-private partnerships**, and build the scientific communities that will ultimately define, develop, and use future quantum computing infrastructure.

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 both bringing users to quantum computers and bringing domain scientists and hardware developers together.** Existing collaborative models have demonstrated the value of multi-institutional partnerships, but stakeholders repeatedly emphasized that truly transformational progress often requires researchers to work side by side for extended periods.

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 be a defining characteristic of the Quantum Challenges Phase.

Finally, quantum computing systems participating in the quantum challenges should enable researchers to understand, characterize, and optimize the underlying hardware rather than treating it as an opaque black box. Appropriate intellectual property protections remain essential; however, the Committee recommends that DOE and its partners develop collaboration frameworks that maximize scientific openness while respecting commercial innovation. Access to hardware architecture, performance characteristics, control interfaces, diagnostics, and system behavior will be critical for enabling meaningful co-design and accelerating scientific discovery.

The Committee therefore recommends **DOE convene a community-based working group** — spanning DOE, the National Laboratories, industry, and academia — to establish this 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 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. Many of these problems have the potential to significantly impact global technology. DOE science can take a global leadership position in working with and guiding industry. With the early fault-tolerant quantum computing era emerging, it is an appropriate time to invest in this direction—consistent with the previous recommendations.

The Committee therefore recommends that **DOE prioritize embedding quantum across all 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.

Similarly, the Committee further recommends integrating quantum computing with DOE's broader science and technology ecosystem—including leadership-class HPC, artificial intelligence, scientific user facilities, advanced technology facilities, experimental platforms, quantum sensing, networking, and data infrastructure—to give an immediate boost and create a unified environment for S&T discovery. Just as high-performance computing has become an indispensable capability across the Office of Science, the Committee envisions quantum computing becoming an integral component of DOE's enterprise.

Finally, to address the gap in co-design and applications, we encourage DOE and partner agencies to establish and expand formal partnerships with agencies such as NIH, USDA, DoD, NASA, NOAA, and DHS. We recommend identifying a selection of problems of interest and creating joint funding mechanisms that pair quantum scientists and engineers with domain experts. This will ensure that quantum technologies are developed against real-world challenge problems and clear pathways to scientific, economic, and societal impact, rather than advancing in search of an end user.

Recommendation 5: Broaden Investments Across the Quantum Technology Stack

The Committee recommends that DOE **broaden investments across the quantum computing technology stack** while building on its longstanding leadership in fundamental quantum science. As quantum computing transitions toward larger computing systems, investments must encompass the scientific and engineering challenges required to realize scalable, fault-tolerant quantum computing. The DOE National Quantum Information Science Research Centers play a key role in this area.

Research areas of continued focus and priority, instrumental to achieve the aggressive 2028 goals include increasing coherence and reducing error rates; understanding and mitigating noise mechanisms and other 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. Future investments should explore architectures in which quantum computers operate in close integration with quantum sensors and scientific instruments, enabling quantum-enhanced experiments, hybrid computing-sensing platforms, and new scientific paradigms. This convergence has the potential to create entirely new capabilities across

DOE mission areas while further **distinguishing the Department's approach to scientific quantum computing.**

The Committee encourages DOE to **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. Applying these unique DOE capabilities to quantum technologies will not only accelerate progress toward fault-tolerant quantum computing but also reinforce DOE's distinctive role in developing scientific instruments that enable transformational discovery.

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 National Quantum Information Science Research Centers, and partnerships spanning the national laboratories, universities, and industry. 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. 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 believes that establishing a future QCUF represents a strategic national investment comparable in ambition to previous landmark DOE scientific initiatives. Achieving this vision will require long-term commitment, stable funding, and coordinated leadership across the Office of Science. The investments recommended in this report will not simply build quantum computers -they will establish a new national capability for scientific discovery, accelerating breakthroughs in medicine, energy, advanced manufacturing, national security, and our understanding of the fundamental laws of nature, while ensuring continued U.S. leadership in one of the defining technologies of the twenty-first century.

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 in quantum hardware, algorithms, software, applications, materials, and enabling technologies 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 this initiative may extend well beyond the scientific challenges identified in this report. By pushing the boundaries of quantum science and engineering, 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.

ALIGNMENT WITH THE QUANTUM GENESIS INITIATIVE

During the preparation of this report, the Administration issued the Executive Order *Ushering in the Next Frontier of Quantum Innovation* and DOE announced the **Quantum Genesis Initiative**, establishing a national strategy to accelerate scientifically useful fault-tolerant quantum computing, strengthen public-private partnerships, and expand the role of quantum technologies.

The Committee finds that the roadmap developed through extensive community engagement is strongly aligned with these national priorities. In particular, the Committee's recommendations provide a science-driven framework that supports Quantum Genesis by organizing future investments around milestone-based scientific progress, multidisciplinary co-design, and rigorous evaluation of scientific utility and technical readiness.

The Committee recommends a phased roadmap in which the **Quantum Challenges Phase** brings together the broader ecosystem to pursue ambitious scientific grand challenges while simultaneously advancing quantum hardware, algorithms, software, artificial intelligence, and systems engineering. Through common scientific and technical milestones, this competitive phase accelerates progress toward scientifically relevant fault-tolerant quantum computing while providing objective evidence to guide future investment decisions.

Successful completion of this challenge phase may justify rigorous evaluation of a **DOE Quantum Computing User Facility (QCUF)** as the next step in advancing quantum computing for scientific discovery. The Committee envisions a future in which quantum computing and related quantum technologies become progressively integrated across the DOE scientific enterprise.

This roadmap also provides a common strategic framework for coordinating DOE's diverse quantum activities while preserving the distinct missions of individual Office of Science programs. Rather than treating quantum computing, sensing, networking, applications, and workforce development as independent efforts, the roadmap establishes shared scientific milestones and a common long-term vision while maintaining the flexibility to adapt as technologies and scientific opportunities evolve. The Committee recommends that the roadmap be periodically reassessed and updated as the field matures, ensuring that future investments remain guided by scientific impact, technical progress, and community needs.

Quantum Genesis Priority	Committee Roadmap
DOE Q Competition	**Quantum Challenges Phase:** milestone-driven scientific grand challenges that advance and validate hardware, algorithms, software, AI, and scientific applications.
Focused R&D for Quantum Computing Applications	**Science-driven co-design:** ambitious scientific challenge problems define technology requirements while broadening the quantum user community and accelerating application development.
National Quantum Supercomputing User Facility	**Quantum Computing User Facility:** a mission-driven scientific user facility, rigorously evaluated based on demonstrated scientific utility, technical maturity, and community readiness, integrated with AI,

	leadership-class HPC, networking, scientific instruments, and data infrastructure.

CONCLUSIONS

The Department of Energy has established one of the world's leading quantum research ecosystems through sustained investments in fundamental science, the National Quantum Information Science Research Centers, and strong partnerships among national laboratories, universities, and industry. The Committee believes the Nation now stands at a pivotal moment where these investments can deliver transformative scientific capabilities.

This report presents a phased roadmap for advancing quantum computing from an emerging technology to a foundational capability for scientific discovery. By organizing future efforts around ambitious scientific grand challenges, multidisciplinary co-design, rigorous milestones, and evidence-based decision making, DOE can accelerate progress toward scientifically useful fault-tolerant quantum computing while continuing to strengthen the outstanding research ecosystem that has positioned the United States as a global leader.

The Committee envisions a future in which quantum computing and related quantum technologies become progressively integrated throughout the DOE scientific enterprise—working alongside leadership-class computing, artificial intelligence, advanced networking, scientific user facilities, and experimental platforms to enable entirely new approaches to discovery. As with previous generations of scientific infrastructure, the greatest impacts are likely to extend well beyond today's envisioned applications, creating new knowledge, new technologies, and new industries that cannot yet be fully anticipated.

The Committee believes that the decisions made during the next several years will shape U.S. leadership in quantum science for decades to come. With sustained national commitment, continued innovation, and close partnership across government, academia, and industry, quantum technologies have the potential to become one of the defining scientific capabilities of the twenty-first century, expanding the frontiers of discovery and delivering lasting benefits to science, the economy, and society.

Achieving the aggressive 2028 goal articulated in the charge will require acceleration beyond current investment and development trajectories. This cannot be accomplished by DOE alone: it will require additional resources and a coordinated whole-of-government effort, leveraging the complementary capabilities and investments of DOE, other federal agencies, the national laboratories, industry, and academia.

APPENDIX A: COMMITTEE MEMBERSHIP

The Committee consisted of leaders from national laboratories, academia, medicine, and the semiconductor industry, bringing complementary expertise spanning quantum hardware, computing systems, scientific applications, technology strategy, and innovation.

Member	Affiliation	Role
Anna Grassellino	Fermilab	Chair
Supratik Guha	University of Chicago / Argonne National Laboratory	Vice Chair
Eric Isaacs	Research Corporation for Science Advancement	Member
Lara Jehi	Cleveland Clinic	Member
Martin Schmidt	Rensselaer Polytechnic Institute	Member
Mark Papermaster	AMD	Member
Tanner Crowder	DOE Office of Science	Designated Federal Officer

The Committee benefited from this multidisciplinary composition, allowing it to consider quantum computing from scientific, technological, industrial, systems engineering, and user community perspectives.

APPENDIX B: COMMITTEE ACTIVITIES & TIMELINE

The Committee conducted an intensive community engagement effort over approximately three months. Major activities included:

Date	Activity
April 2026	Committee established and initial planning meetings
April-May	Definition of roadmap framework, interview strategy, and community engagement plan
May	Public Request for Information (RFI) released
May-June	Stakeholder interviews with leaders from industry, academia, national laboratories, federal agencies, and international organizations
June 12	DOE Office of Science Community Town Hall
June	Committee deliberations and synthesis
July	Final report presented to SCAC

The engagement strategy was intentionally designed to gather perspectives from across the national and international quantum ecosystem while ensuring representation of both technology developers and scientific user communities.

APPENDIX C: STAKEHOLDER INTERVIEWS

The Committee conducted more than **30 one-hour structured interviews** with leaders representing industry, academia, national laboratories, federal agencies, and international organizations. Interviews followed a common set of questions focused on:

- *the current state of quantum computing;*
- *scientific opportunities;*
- *technology milestones toward fault-tolerant quantum computing;*
- *the concept of a DOE Quantum Computing User Facility;*
- *public-private partnerships; and*
- *future investment priorities.*

The interview process intentionally brought together stakeholders spanning the entire quantum computing ecosystem, including chief scientists and senior technical leaders from the world's leading quantum computing companies; directors and senior scientists from DOE national laboratories and DOE National Quantum Information Science Research Centers (NQISRCs); internationally recognized academic researchers; leaders of major computing, networking, and user-facility programs; experts from European quantum initiatives and CERN; and scientific application specialists working across chemistry, materials science, particle physics, nuclear physics, optimization, biology, and high-performance computing. This broad representation allowed the Committee to capture perspectives from both technology developers and future scientific users, while incorporating expertise across multiple hardware modalities, quantum architectures, and scientific domains. Stakeholders included representatives from:

- *leading quantum computing companies with mature QC platforms (IBM, Google, Quantinuum, IonQ, Rigetti, QuEra, D-Wave, Infleqtion, PsiQuantum);*
- *DOE National Laboratories and DARPA leaders;*
- *major academic and international institutions: CERN and European quantum initiatives;*
- *quantum application experts spanning chemistry, materials science, particle physics, nuclear physics, optimization, and biology.*

Major Themes Emerging from Stakeholder Interviews

The field has entered a transition toward fault-tolerant quantum computing

Interviewees broadly agreed that quantum computing has entered a new phase characterized by the emergence of logical qubits and practical quantum error correction. While substantial scientific and engineering challenges remain, there was broad consensus that the next three years represent a unique opportunity to transition from laboratory demonstrations toward the first scientifically meaningful fault-tolerant quantum computations. Most stakeholders viewed 2028 as an appropriate target for demonstrating scientific utility, provided coordinated investments continue across hardware, algorithms, software, and systems engineering.

Scientific applications should drive the roadmap

Stakeholders consistently emphasized that future investments should be driven by compelling scientific applications rather than hardware metrics alone. Frequently cited application areas included chemistry, materials science, condensed matter physics, particle physics, nuclear physics, fusion energy science, biology, optimization, and quantum-enhanced sensing. Many stressed that success should ultimately be measured by the ability to solve important scientific problems that are beyond the reach of classical computation, with hardware, algorithms, and software developed through close co-design with domain scientists. Several interviewees also highlighted the emerging opportunity to couple quantum computing with quantum experiments and sensing platforms to enable entirely new scientific workflows.

A DOE Quantum Computing User Facility could play a unique national role

Interviewees strongly supported the concept of a DOE Quantum Computing User Facility at DOE labs as a national scientific resource that extends beyond providing access to quantum processors. The envisioned facility would integrate quantum computing with high-performance computing, artificial intelligence, networking, scientific instruments, data infrastructure, and advanced software environments. Many described the facility as an integrated scientific platform enabling co-design among hardware developers, algorithm researchers, computational scientists, and scientific users. Several stakeholders also suggested that the facility should initially evolve through staged testbeds and scientific campaigns before transitioning to larger production-class systems.

Integration with classical computing and scientific infrastructure

Multiple stakeholders emphasized that future quantum computers should function as tightly integrated components of broader scientific computing ecosystems rather than as stand-alone systems. Integration with HPC, AI, workflow orchestration, networking, data infrastructure, and experimental facilities was repeatedly identified as essential for achieving scientific utility. Several interviewees highlighted that computational scientists and algorithm developers should work in close proximity to quantum hardware, enabling rapid co-design and hybrid quantum-classical workflows that maximize scientific impact, but that physical co-location of HPC and quantum computers is not technically necessary.

DOE should build an open, technology-neutral ecosystem

A strong consensus emerged that DOE should leverage rapid industrial innovation while maintaining an open, technology-neutral scientific environment. Interviewees consistently advised against prematurely selecting a single hardware modality, noting that significant scientific and engineering uncertainties remain across superconducting, trapped-ion, neutral-atom, photonic, and other emerging platforms. Instead, stakeholders recommended supporting multiple modalities, common benchmarking, and open interfaces while allowing scientific applications and demonstrated performance to guide future technology evolution. Several industry leaders emphasized that DOE's unique comparative advantage lies in system integration, scientific benchmarking, user access, and long-term infrastructure rather than commercial hardware development.

Systems engineering, manufacturability, and scalability have become important technical challenges

While continued improvements in qubit fidelity remain critical, many interviewees emphasized that some of the important obstacles to large-scale fault-tolerant systems include systems engineering challenges. Frequently cited priorities included scalable control electronics, manufacturability, cryogenic infrastructure, networking, modular architectures, real-time decoding, software infrastructure, and reliable operation of increasingly complex quantum systems. Several stakeholders noted that demonstrating these capabilities over the next three years will be as important as increasing logical qubit counts.

Clear gating milestones should guide facility readiness

Many interviewees recommended that DOE establish objective scientific and technical readiness criteria before initiating construction of a user facility. Suggested milestones included demonstrations of scalable logical qubits, logical error rates approaching 10^{-7}–10^{-9}, multi-logical-qubit operations, scalable error-correction protocols, magic-state distillation, quantum networking, and benchmark scientific applications that clearly demonstrate utility beyond classical computing. Several stakeholders argued that procurement and facility decisions should be driven by demonstrated capability and benchmarked scientific performance rather than vendor roadmaps alone.

Public-private partnerships will be central to success

Interviewees consistently recommended that DOE build upon the rapid progress occurring in industry while focusing federal investments on enabling scientific applications, co-design, benchmarking, workforce development, shared infrastructure, and long-term research challenges. National laboratories were widely viewed as natural integrators capable of bringing together industry, academia, and scientific users to accelerate both technology maturation and scientific discovery. Several stakeholders also emphasized that DOE should support open architectures, collaborative software development, and flexible partnership models that encourage broad participation across the quantum ecosystem.

A DOE Quantum Computing User Facility should not simply be a place that hosts quantum computers—it should be a scientific innovation ecosystem.

Across nearly every interview, stakeholders described the facility as:

- *a place where hardware, architectures, algorithms, AI, HPC, networking, and experiments are co-developed;*
- *a center for scientific campaigns rather than just compute allocation;*
- *a platform for long-term partnerships among industry, national laboratories, universities, and users;*
- *and a catalyst for building a national quantum workforce.*

This has the potential to distinguish the DOE role from commercial cloud offerings and captures what makes a DOE user facility uniquely valuable. It also ties directly into the DOE vision of integrating quantum computing with the DOE **Genesis** ecosystem and other Office of Science user facilities.

APPENDIX D: COMMUNITY INPUT REQUEST

To complement the stakeholder interviews, the Committee issued a public Community Input Request (CIR) inviting written input from the broader quantum information science community. The announcement requested perspectives on the vision for a future DOE Quantum Computing User Facility, technology milestones, scientific applications, algorithms and software, systems integration, workforce development, and collaboration models.

The CRI emphasized that the roadmap should serve both as a near-term plan to achieve meaningful scientific utility by 2028 and as a long-term vision for a transformative national capability that supports the Office of Science over the coming decade. Approximately **50 written responses** were received from stakeholders spanning academia, industry, national laboratories, nonprofit organizations, and individual researchers. Collectively, these submissions reinforced the major themes that emerged during the public engagement process while providing additional technical detail on facility architecture, technology milestones, scientific applications, software, workforce development, and operating models.

Several overarching themes emerged consistently across the written submissions.

Broad support for a DOE Quantum Computing User Facility

There was overwhelming support for DOE establishing a Quantum Computing User Facility as a national scientific resource.

Nearly every submission emphasized that the facility should not simply provide access to quantum processors, but instead function as an integrated scientific computing platform combining

- *quantum computing,*
- *high-performance computing,*
- *AI,*
- *networking,*
- *scientific data infrastructure,*
- *quantum sensing,*
- *and experimental user facilities.*

Many respondents noted that the facility should resemble existing DOE scientific user facilities rather than commercial cloud computing services.

Scientific impact should define success

A recurring recommendation was that progress should be measured by scientific capability rather than hardware metrics alone.

Many respondents argued that milestones based solely on physical qubit counts risk encouraging technology demonstrations without meaningful scientific impact. Instead, they recommended evaluating progress through

- *logical qubit performance,*

- *error-corrected computations,*
- *reproducible scientific workflows,*
- *demonstrated scientific quantum advantage,*
- *and solutions to scientifically relevant DOE problems.*

Several submissions explicitly argued that "scientific utility" rather than "largest quantum computer" should define success.

Integration emerged as the defining characteristic

Perhaps the strongest consensus across submissions was that integration—not processor size—will determine the success of a DOE facility.

Respondents consistently proposed integrating the following into unified workflows.

Several submissions explicitly described the facility as a "hybrid" or "convergent" scientific platform rather than a standalone quantum computer.

Support multiple hardware modalities

There was broad agreement that DOE should avoid prematurely selecting a single winning hardware technology.

Instead, respondents recommended maintaining a diverse portfolio including superconducting qubits, trapped ions, neutral atoms, spin qubits, photonic approaches, and future emerging technologies.

Many submissions argued that supporting multiple modalities would reduce technical risk while encouraging scientific comparison and co-design.

Flexible prototypes are as important as production systems

Many responses emphasized that the facility should include both:

- *production-scale user systems*
- *flexible experimental prototypes*

Prototypes were viewed as essential for:

- *hardware innovation,*
- *architecture exploration,*
- *software development,*
- *algorithm validation,*
- *benchmarking,*
- *and rapid technology evolution.*

Several laboratories argued that flexibility should remain a defining feature even after fault-tolerant systems become available.

Hybrid quantum-classical computing

Nearly every submission envisioned hybrid quantum-classical workflows.

Rather than replacing HPC, respondents consistently viewed quantum processors as accelerators integrated into larger scientific workflows. Respondents highlighted how classical – quantum integration does not require physical co-location nor tight coupling in the near future.

High-impact scientific applications

The written responses identified a remarkably consistent set of scientific drivers for quantum computing, including:

- *quantum chemistry,*
- *catalysis,*
- *strongly correlated materials,*
- *superconductivity,*
- *molecular science,*
- *lattice gauge theories,*
- *high-energy physics,*
- *nuclear many-body systems,*
- *fluid dynamics,*
- *optimization,*
- *quantum machine learning,*
- *fusion science,*
- *and biological sciences.*

Many respondents emphasized that DOE should prioritize applications that naturally exploit quantum mechanics rather than generic computational workloads.

Software and benchmarking deserve equal emphasis. Numerous responses argued that software infrastructure will become a major bottleneck. Recommendations included:

- *portable software stacks,*
- *standardized APIs,*
- *interoperable programming environments,*
- *resource estimation,*
- *workflow orchestration,*
- *compiler development,*
- *verification tools,*
- *benchmark suites,*
- *and logical-level performance metrics.*

Several submissions stressed that benchmark results should remain independent, reproducible, and continually compared against the best available classical algorithms.

Partnerships across the ecosystem

Respondents consistently advocated a partnership model involving

- *DOE laboratories,*
- *universities,*
- *industry,*
- *startups,*
- *federal agencies,*
- *and international collaborators.*

Many envisioned DOE serving as the integrator that brings together technologies developed across the broader ecosystem while maintaining open scientific access.

Workforce development

Many submissions identified workforce development as a strategic priority. Suggested activities included:

- *interdisciplinary education,*
- *software training,*
- *hardware access,*
- *quantum centers,*
- *user support,*
- *fellowships,*
- *and sustained engagement with scientific users.*

Several respondents argued that cultivating a broad scientific user community is as important as advancing the underlying hardware.

Additional themes

Several submissions highlighted additional areas that provided valuable input for future planning, including:

- *scalable cryogenic infrastructure and quantum data centers;*
- *integration of quantum sensing and networking with computing;*
- *facility-scale fabrication and materials characterization capabilities;*
- *quantum digital twins for system validation;*
- *AI-enabled facility operations;*
- *open hardware interfaces and user programmability;*

- *long-term technology roadmaps extending beyond the 2028 milestone.*

Overall observations

Taken together, the written submissions demonstrated a high degree of convergence across the quantum research community. Despite representing diverse institutions and perspectives, contributors consistently envisioned a DOE Quantum Computing User Facility as an integrated scientific platform rather than simply a collection of quantum processors. The responses emphasized that long-term success will depend on coupling quantum hardware with high-performance computing, artificial intelligence, scientific instruments, networking, and a broad user community, while measuring progress through scientific discovery rather than hardware metrics alone.

APPENDIX E: COMMUNITY TOWN HALL

On **June 12, 2026**, the Committee hosted a one-day virtual Community Town Hall to provide an open forum for the quantum information science community to contribute directly to the roadmap.

The Town Hall attracted approximately **490 registered participants**, with **42 invited presentations** selected from more than **100 submitted abstracts**, representing broad participation from industry, academia, national laboratories, and federal agencies.

The program was organized into five thematic sessions that directly mirrored the structure of the emerging roadmap:

1. State of the Art, Technical Challenges, and Milestones
2. Vision for a Transformative DOE Quantum Computing User Facility
3. High-Impact Scientific Applications and Near-Term Opportunities
4. Algorithms, Software, Classical–Quantum Integration, and Computational Requirements
5. Collaboration, Ecosystem Advancement, and Program Models.

Together with the stakeholder interviews and written CIR responses, the Town Hall provided a comprehensive community perspective that informed the Committee's findings, recommendations, and proposed roadmap.

Community Town Hall – Summary of Key Messages

Broad consensus around the 2028 milestone

Participants broadly supported the DOE Office of Science vision of achieving a scientifically meaningful demonstration on an error-corrected quantum computer by 2028. While recognizing the ambitious nature of this goal, speakers emphasized that recent advances in logical qubits, quantum error correction, and system integration have fundamentally changed the outlook for the field. Many viewed the coming three years as a critical transition from proof-of-principle demonstrations toward scientific utility.

Several speakers noted that the 2028 milestone should not be measured solely by hardware metrics such as logical qubit count, but rather by demonstrating solutions to scientifically important problems that are beyond the practical reach of existing approaches.

Scientific applications should drive technology development

One of the strongest recurring themes throughout the Town Hall was that scientific applications should become the primary driver for future quantum computing development.

Rather than optimizing hardware in isolation, speakers advocated close co-design between quantum hardware developers, algorithm researchers, and domain scientists. Numerous DOE mission areas were identified as compelling early application targets, across the DOE Office of Science missions.

Several presentations emphasized identifying "moonshot" scientific problems capable of demonstrating transformative quantum advantage while simultaneously driving hardware and algorithm requirements.

A DOE Quantum Computing User Facility should be more than acquiring hardware

Speakers consistently emphasized that a future DOE Quantum Computing User Facility should not simply provide access to commercial quantum processors. Instead, participants envisioned an integrated scientific platform that combines DOE science missions and facilities with quantum capabilities. Architectures would be co-developed to target particular scientific problems.

Many presentations highlighted successful aspects of existing DOE user access programs, particularly the importance of

- *Rapid, transparent and merit-based proposal review,*
- *broad community access,*
- *technical support teams,*
- *fast turnaround,*
- *and close interaction between users and facility staff.*

Participants viewed these capabilities as essential for enabling a broad quantum scientific user community.

Hybrid quantum-classical workflows will dominate the near term

Rather than expecting quantum computers to replace classical HPC, discussions envisioned tightly integrated hybrid workflows.

Speakers described future scientific computing environments in which AI, classical simulation, HPC, and quantum processors operate together, with each technology solving the portion of the workflow best suited to its strengths.

Several presenters argued that the earliest demonstrations of scientific value are likely to emerge from hybrid workflows rather than fully standalone quantum algorithms.

Technology priorities extended beyond increasing qubit counts

Although continued improvements in logical qubit fidelity and error correction were viewed as essential, many participants highlighted additional technology priorities, including

- *high coherence and lower multi-qubit gate error rates,*
- *improved qubit connectivity,*
- *scalable cryogenic systems,*
- *modular architectures,*
- *compiler and software stack development,*
- *integration with classical computing infrastructure,*
- *benchmarking standards,*
- *and reliable system-level engineering.*

Several speakers emphasized that progress in these enabling technologies could substantially accelerate scientific applications even before very large-scale fault-tolerant systems become available.

Community interest extended well beyond traditional quantum applications

The Town Hall demonstrated that potential users span a remarkably broad scientific community.

Many speakers stressed that expanding engagement beyond the traditional quantum information science community will be essential for maximizing scientific impact and ensuring that future facilities address the needs of a broad DOE user base.

Workforce development and open access were viewed as critical enabling investments

Across multiple sessions, participants emphasized that the success of a future DOE Quantum Computing User Facility will depend not only on technology development but also on cultivating a broad user community. Recommendations included:

- *lowering barriers to facility access,*
- *providing training and educational resources,*
- *supporting interdisciplinary collaborations,*
- *developing community software tools,*
- *creating opportunities for early-career researchers,*
- *and enabling close partnerships among national laboratories, universities, and industry*.

Many speakers emphasized that building a sustainable national quantum workforce should be viewed as an essential outcome of the roadmap rather than a secondary benefit.

Overall observations

The Town Hall revealed a strong consensus that the quantum computing community has entered a pivotal stage in its development. Participants broadly agreed that the next several years represent a unique opportunity to align advances in quantum hardware, algorithms, artificial intelligence, high-performance computing, and scientific applications toward a common national objective. Across all sessions, speakers consistently supported the development of a DOE Quantum Computing User Facility as an integrated scientific capability designed not only to accelerate technology development but also to enable transformative scientific discovery across the Office of Science.

AREAS OF DIVERGENCE & OPEN QUESTIONS

While there was strong consensus on the long-term vision and the importance of accelerating quantum computing for scientific discovery, stakeholders expressed a range of views on several important questions that remain active areas of discussion. These differences reflect the rapidly evolving nature of the field and underscore the importance of maintaining a flexible, milestone-driven roadmap.

Technology pathways and timelines: Although there was broad agreement that fault-tolerant quantum computing is becoming increasingly realistic, stakeholders differed significantly in their expectations for the pace of progress. Some anticipated the demonstration of scientifically useful fault-tolerant systems by 2028, while others viewed large-scale fault tolerance as requiring a substantially longer timeframe. Similarly, opinions differed on the relative maturity and long-term potential of different hardware modalities, reinforcing the need for a technology-neutral strategy that supports multiple approaches while allowing performance and scientific utility to guide future investment.

Facility architecture and deployment model: Interviewees proposed several models for a future DOE Quantum Computing User Facility. Some envisioned a single leadership-class national facility, while others advocated a distributed network of complementary facilities or specialized platforms across multiple national laboratories. Views also differed on the balance between cloud-based access and on-premises systems, with many recommending a hybrid approach that evolves as the technology matures.

Technology versus applications: While there was broad agreement that scientific applications should ultimately drive the roadmap, stakeholders expressed different perspectives on the near-term balance between investments in enabling technologies and investments in application development. Some emphasized the need to first solve key hardware and systems-engineering challenges before large-scale application efforts can succeed, whereas others argued that aggressive application co-design is essential to ensure that technology development remains aligned with compelling scientific opportunities.

Role of DOE within the broader ecosystem: Stakeholders shared a common view that DOE should complement, rather than duplicate, industrial efforts, but differed on the degree to which DOE should directly host frontier quantum hardware versus serving primarily as an enabler and integrator of various technologies. Likewise, there were differing perspectives on the appropriate balance between open scientific infrastructure, public-private partnerships, and support for proprietary technology development.

Despite these differences, the Committee found remarkable convergence on the overarching direction of the field. Across all stakeholder groups, there was broad agreement that scientific applications requires additional future investments, that quantum computing should evolve as part of an integrated scientific computing ecosystem, and that the coming three years provide a critical opportunity to establish the scientific, technological, and community foundations needed to enable a future DOE Quantum Computing User Facility.

The Committee intentionally did not seek to resolve these technical debates. Instead, it used them to develop recommendations that are sufficiently flexible to accommodate continued innovation while defining objective scientific and technical milestones that can guide future investment decisions.

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arXiv:2607.26962
The newest reference in the list; synchrotron strain mapping of the qubit host.

Modularity, Networking & Interconnects

29. Y. Zhou, Y. Wu, C. Li, M. Shen, L. Yang, J. Xie, H. X. Tang
A 1-km Photonic Link Connecting Superconducting Circuits in Two Dilution Refrigerators
Nature Photonics 20, 579–585 (2026)
doi:10.1038/s41566-026-01866-7• C2QA highlight
The direct experimental anchor for the modular-architecture row in Table 3.

530. M. Saha, Y. H. Wen, A. S. Greenspon, M. Zimmermann, K. J. Palm, A. Witte, Y. M. Goh, C. Li, J. Bumstead, K. Schädler, et al. (17 authors)
Nanophotonic Waveguide Chip-to-World Beam Scanning
Nature 651, 356–363 (2026)
doi:10.1038/s41586-025-10038-6
Integrated photonic beam delivery — the scaling path for optical control of atoms and ions.

Software, Compilers, Benchmarking & HPC/AI Integration

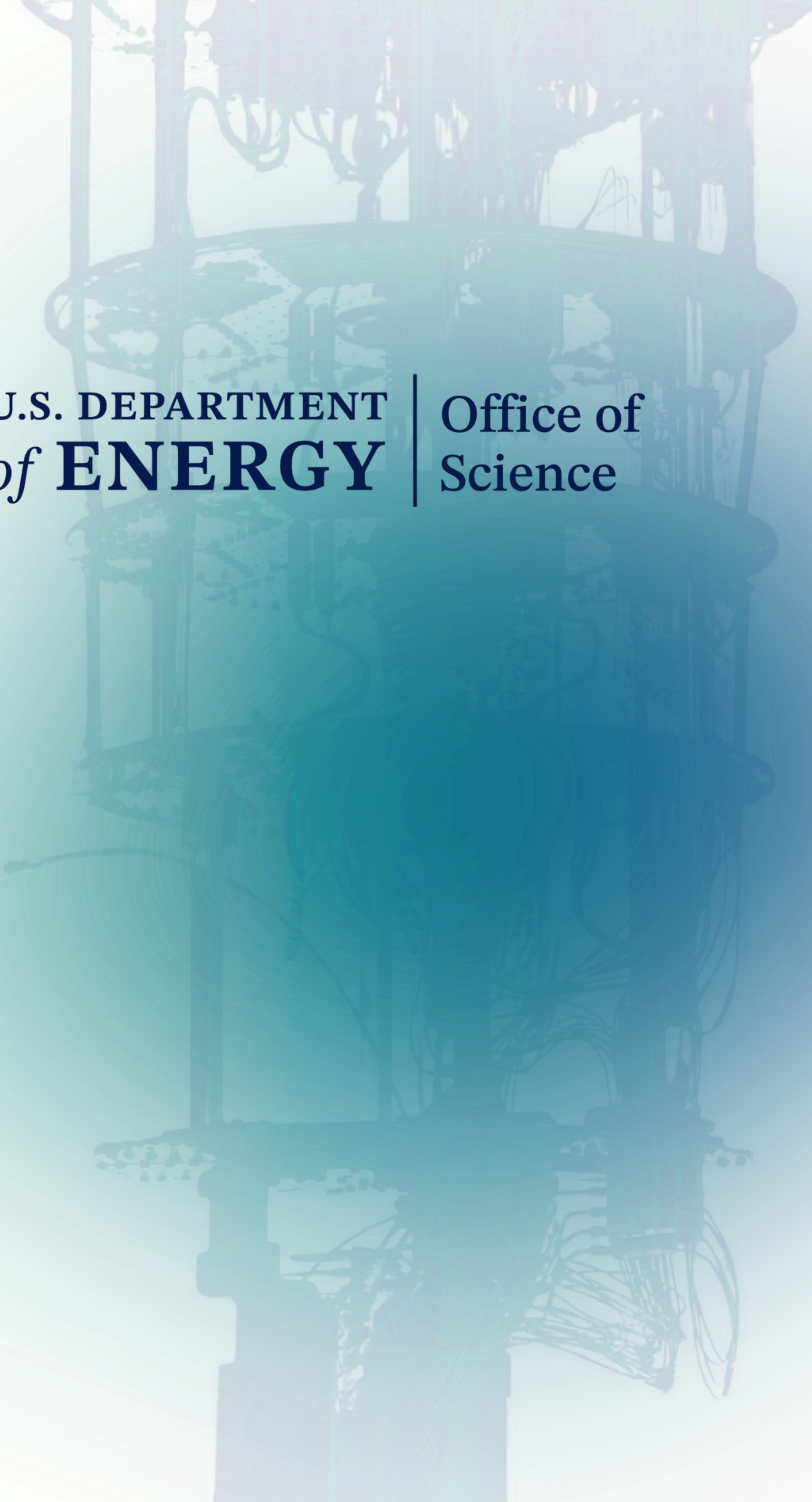
1. A. Harkness, S. Kan, C. Liu, M. Wang, J. M. Martyn, S. Xu, D. Chamaki,
E. Decker, Y. Mao, L. F. Zuluaga, et al. (13 authors)
FTCircuitBench: A Benchmark Suite for Fault-Tolerant Quantum Compilation and Architecture

Preprint, 6 January 2026
arXiv:2601.03185
A common benchmark for fault-tolerant compilation — the concrete instrument behind Table 3's software-and-compilers row.

2. K. Yin, H. Zhang, X. Fang, Y. Shi, T. S. Humble, A. Li, Y. Ding
QECC-Synth: A Layout Synthesizer for Quantum Error Correction Codes on Sparse Architectures
ASPLOS '25: Proc. 30th ACM Int. Conf. on Architectural Support for Programming Languages
and Operating Systems, Vol. 1, 876–890 (2025)
doi:10.1145/3669940.3707236
Automated mapping of QEC codes onto hardware that is not all-to-all — the modality-neutral statement
of the qLDPC layout problem.

3. A. Shehata, B. Austin, T. Beck, L. Burgholzer, A. Chernoguzov, S. Churchill,
A. Delgado, Y. Eckert, J. Heckey, K. Kissell, et al. (25 authors)
Quantum-HPC Software Stacks and the openQSE Reference Architecture: A Survey
Preprint, 22 April 2026; revised 15 June 2026
arXiv:2604.20912
Multi-institution survey plus a proposed reference architecture for quantum-HPC integration.

34. N. Stapleton, S. Afrose, E. Seefried, V. Leyton Ortega, T. S. Humble, T. Ghosal
Quantum-RAG: Retrieval-Augmented Generation Framework for Quantum Circuit Code Generation
2026 IEEE 19th Dallas Circuits and Systems Conference (DCAS), 1–5 (2026)
doi:10.1109/DCAS69364.2026.11544968
AI-assisted circuit code generation; the AI-integration example in the submissions.



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