U.S. DEPARTMENT OF ENERGY | Office of Science

National Quantum Information Science Research Centers

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Advanced Scientific Computing Research
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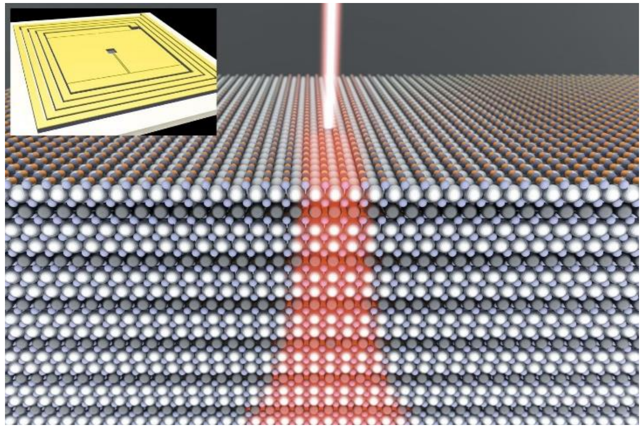
Office of Science has a multi-decade history of foundational support underpinning QIS

- High performance computing, simulation, modeling, and networking support
- Quantum materials
- Sensors and Detectors
- Cryogenics, SRF technologies
- Unique capabilities for synthesis, fabrication, characterization, prototyping, and measurements
- Large team-based approaches, and workforce development



Research into Josephson junctions supported by BES led in 1985 to the discovery that SQUIDs exhibited multiple quantum levels or states—the first time such phenomena, common in atoms, had been observed in much larger, man-made devices. BES-supported research in this and related areas continued for several decades.

QIS Crosses the Technical Breadth of the Office of Science

ASCR
Algorithms; Computer Science; Networking; Testbeds

NP
Many Body Systems; QIS Ready Workforce

BES
Quantum Systems and Computing: model, make, and measure

HEP
Field theory; dark matter; gravity; event tracking; fundamentals

FES
Qubit synthesis; ion traps; Fusion Plasma modeling

BER
Bioimaging applications, sensing and measurement capabilities

Fundamental Science

Quantum Computing

Quantum Communication

Quantum Sensing

Intellectual Capital Based on 100+ Years

Large-Scale & Long-Term Investments for Interdisciplinary Teams with Specific Focus

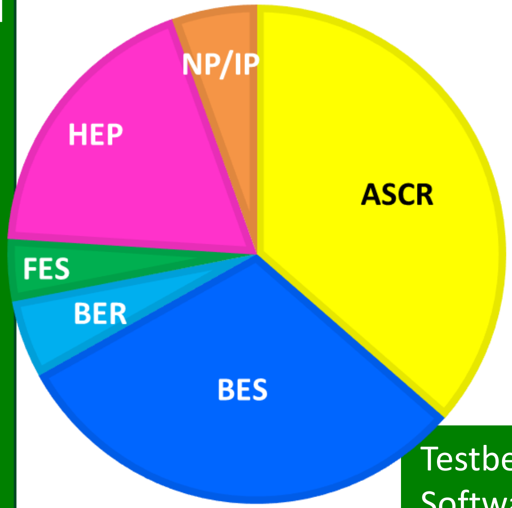
Key Supporting Technologies (e.g. Isotope research, production & enrichment by IP)

Leadership in Launching Internationally-Recognized Collaborative Programs

SC Unique Strengths to Advance Basic Science and Quantum Based Technology

Office of Science Has Been Ramping Up Its QIS Investments Since 2017

$250M



FY 2017
- Algorithms
- QC Hardware
- Pilot Projects

FY 2018
- Testbeds
- Software Stack
- Bioimaging
- QIS Applications
- Materials
- NSRCs & EFRCs
- Fundamental Physics
- Algorithms
- QC Hardware

FY 2019
- Quantum Networks
- Testbeds
- Software Stack
- Bioimaging
- QIS Applications
- Materials
- NSRCs & EFRCs
- Fundamental Physics
- Algorithms
- QC Hardware

FY 2020
- QIS Research Centers
- Quantum Networks
- Testbeds
- Software Stack
- Bioimaging
- QIS Applications
- Materials
- NSRCs & EFRCs
- Fundamental Physics
- Algorithms
- QC Hardware

FY 2021
- Quantum Internet
- QIS Research Centers
- Quantum Networks
- Testbeds
- Software Stack
- Bioimaging
- QIS Applications
- Materials
- NSRCs & EFRCs
- Fundamental Physics
- Algorithms
- QC Hardware

DOE-SC National QIS Research Centers

- Authorized by and consistent with the National Quantum Initiative Act, signed into law in December 2018
- First large-scale QIS effort that crosses the technical breadth of SC
- Scope built on extensive community-wide RFI inputs– from technical scope to partnership model to management construct

- Significant National Impact
- Major Cross-Cutting Challenge
- Science and Technology Innovation Chain
- QIS Ecosystem Stewardship
- Multi-Disciplinary Leadership
- Collaborative Management Structure
- Well-Structured Plan and Metrics

DOE-SC National QIS Research Centers FOA Review Process

February 10th | April 17th | End of June-Mid-August | August 26th

Pre-Proposals

- Responsiveness Review
- Competitiveness Review (Internal Reviewers)

Proposals

- Responsiveness Review
- Merit Review (External Reviewers)

Pre-Selection

- Interviews
- Clarification

Selection

- Merit Review Recommendations
- Pre-selection interviews
- Pre-selection clarification
- SC National QIS Research Centers WG recommendations
- Program policy factors

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Five DOE-SC National QIS Research Centers

Q-NEXT • Next Generation Quantum Science and Engineering
(David Awschalom, ANL)

C^{2}QA • Co-design Center for Quantum Advantage
(Steve Girvin, BNL)

SQMS • Superconducting Quantum Materials and Systems Center
(Anna Grassellino, FNAL)

- ✓ QIS S&T Innovation Chain
- ✓ Technical Areas of Interest
- ✓ QIS Ecosystem Stewardship
- ✓ Management Structure
- ✓ Instrumentation and Facilities

QSA • Quantum System Accelerator
(Irfan Siddiqi, LBNL)

QSC • The Quantum Science Center
(David Dean, ORNL)

https://science.osti.gov/Initiatives/QIS

Q-NEXT
Next Generation Quantum Science and Engineering

A focused, connected ecosystem to deliver quantum interconnects, to establish national foundries, and to demonstrate communication links, networks of sensors, and simulation testbeds.

Promoting U.S. competitiveness with impactful science
5-year goals include repeater-enabled quantum interconnects, networked ultra-precise sensors, and a national resource for quantum materials.

Creating industrial engagement at all levels
10 U.S. member companies, leaders in their respective fields, provide pathways to the practical commercialization of quantum technology. *Q-NEXT will host the Intel Solid State Quantum Test Bed at Argonne*.

Training a quantum smart workforce
The Q-NEXT NEXT-GEN program builds on the successful NSF QISE-NET program to pair students with co-advisors at industry and National Laboratories. Q-NEXT will broaden access to quantum academic degrees and certifications.

Developing quantum standards
Incorporating processes, metrology, and tests into a National Quantum Devices Database.

Forging connectivity across the quantum ecosystem
Creating new synergies between investments in quantum research centers and leveraging world-class facilities including 3 light sources, Argonne's leadership computing facility, and its nanoscience center. *Quantum foundries at ANL and SLAC.*

3
National Labs

10
Universities

10
Industry Partners

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q-next.org

C²QA
Co-design Center for Quantum Advantage

THE PROBLEM

Quantum computers have the potential to solve scientific and other kinds of problems that would be practically impossible for traditional supercomputers. Current Noisy Intermediate-scale quantum computers suffer from a high error rate due to noise, faults and loss of quantum coherence.

OUR GOAL

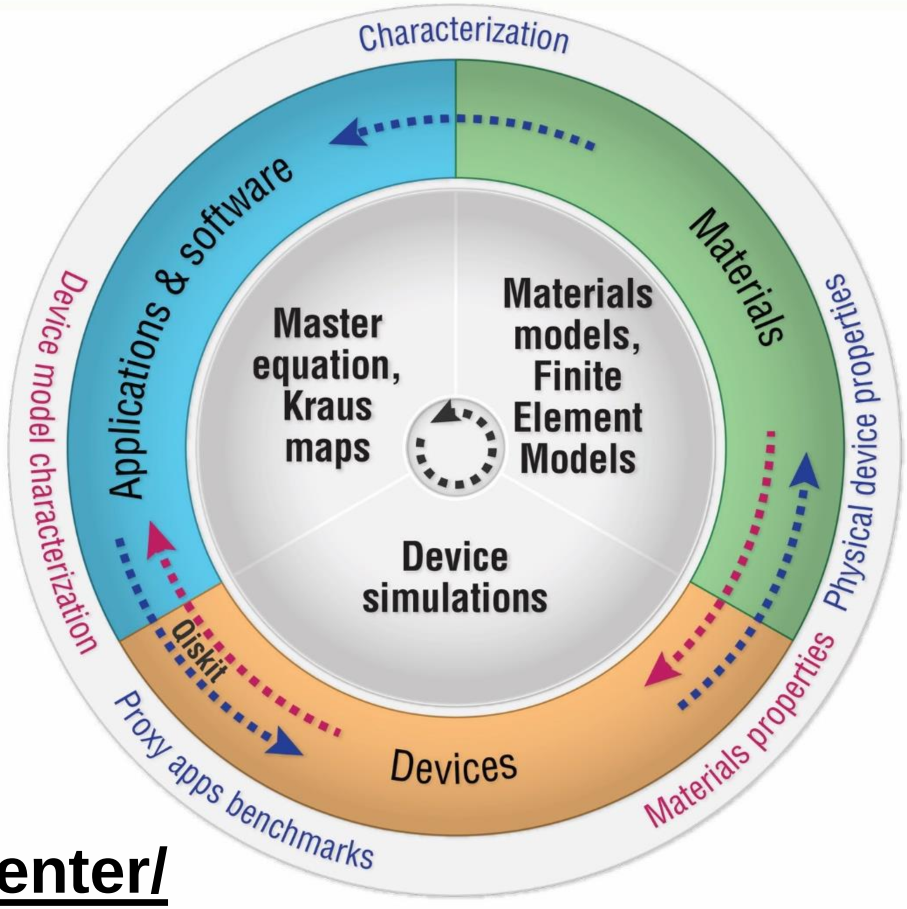
Through materials, devices, and software co-design efforts, our team will understand and control material properties to extend coherence time, design devices to generate more robust qubits, optimize algorithms to target specific scientific applications, and develop error-correction solutions.

OUR APPROACH

Our interdisciplinary team of world-leading scientists will integrate expertise across the Center's 24 partner institutions to develop co-design tools and benchmarks, develop and discover new materials and qubit devices and architectures.

WHAT IS CO-DESIGN

Traditional co-design is the joint design of hardware and software. We will develop and apply quantum co-design principles to target three research thrusts: Algorithms and Software, Devices and Materials.



BUILDING THE U.S. WORK FORCE OF THE FUTURE

Enhancing the quantum educational programs already underway at our team institutions, we will expand upon the quantum processing, quantum mechanics and quantum computing knowledge to develop programs for the general public, K-12 students, internships and training, career events, and online resources and videos.

MORE INFO

For more information:
www.bnl.gov/quantumcenter

bnl.gov/quantumcenter/

SQMS

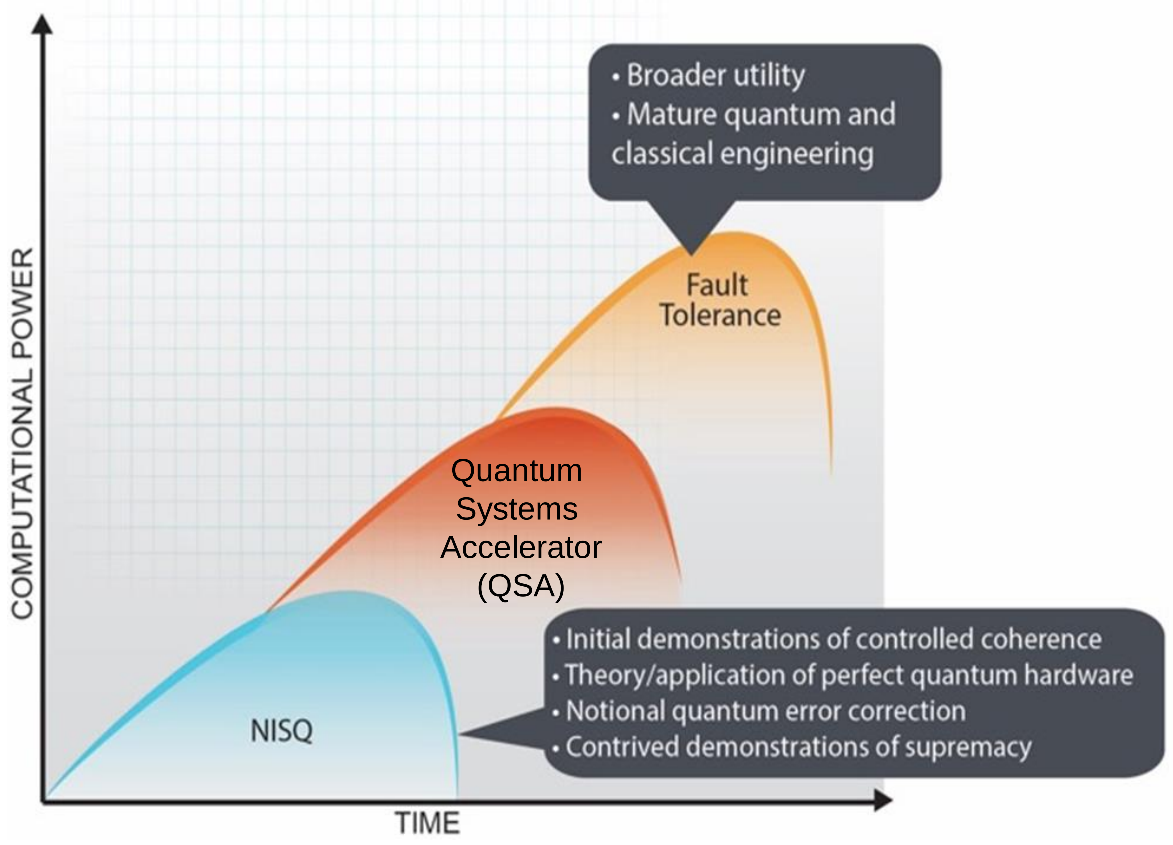
Superconducting Quantum Materials and Systems Center

Transformational advances in understanding and eliminating decoherence mechanisms in superconducting 2D and 3D devices, to enable construction and deployment of superior quantum systems for computing and sensing; foundry capabilities and quantum testbeds for materials, physics, algorithms, and simulations

sqms.fnal.gov

QSA
Quantum Systems Accelerator

Simultaneous advancement of the science underpinning the materials, controls, architectures, algorithms and new engineering disciplines needed to, ultimately, establish quantum systems as a mature, scalable technology.



Harnessing Quantum

QSA will address how quantum complexity can be transformed into an engineering resource.

Programming Quantum

QSA will establish the precision tools to control naturally occurring atomic qubits and better engineered superconducting qubits for existing classical controls.

Engineering Quantum

QSA will establish metrics, benchmarks, and technology roadmaps to guide industry and bring quantum from the laboratory to the factory.

Engaging Quantum

QSA will establish a stable platform for cooperative research and a launchpad for young and mid-career scientists and engineers.

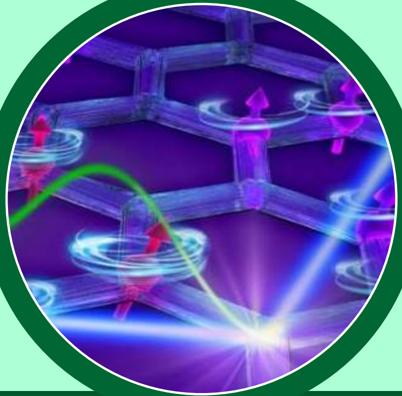
quantumsystemsaccelerator.org

QSC
The Quantum Science Center

Overcoming roadblocks in quantum state resilience & controllability to enable scalable quantum technologies

Thrust 1

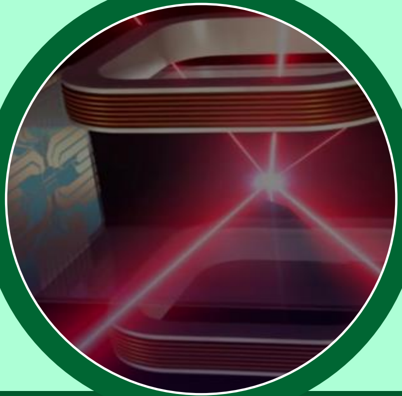
Address the fragility of quantum states through the **design of new topological materials** for QIS



Accelerated quantum information processing

Thrust 2

Develop **algorithms and software** for computation and sensing with current and future QIS hardware



Prediction of new physical and chemical behaviors

Thrust 3

Design new **quantum devices and sensors** to detect dark matter and topological quasiparticles

New quantum sensing capabilities to explore the previously unmeasurable

qscience.org

DOE-SC National QIS Research Centers Portfolio

S&T Innovation Chain with Targets

Applications
Computing, communications and sensing for science and industry

Prototypes
Computing, sensing, network testbeds

Systems
SRF cavities, QPUs, detectors

Devices
Superconducting, ion trap, neutral atom, topological qubits, national quantum devices database, sensors, repeaters

Fundamental Science
Materials, theory, foundries, algorithms, software

Complementary Technical Areas of Interest

- Quantum Communication
- Quantum Computing and Emulation
- Quantum Devices and Sensors
- Materials and Chemistry for QIS Systems and Applications
- Quantum Foundries

Office of Science programs well-covered

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DOE-SC National QIS Research Centers Portfolio

Diverse Management Structures

- Center Directors: 4 senior males, 1 mid-career female
- Deputy Directors: 4 males, 1 female; 4 senior, 1 early-career; 3 labs, 2 universities
- Recognition of project management best practices: ECP-like (ORNL) to Lean (FNAL)
- BEST experts in the world, clear commitment to significant national impact

Instrumentation & Facilities

- Full leverage of DOE facilities across the lab complex
- Building new capabilities: e. g. ANL and SLAC quantum foundries
- Incorporating industry: e. g. Q-NEXT (Intel testbed)
- Using international facilities: e.g. SQMS (Gran Sasso, largest underground laboratory in the world)

QIS Ecosystem Stewardship

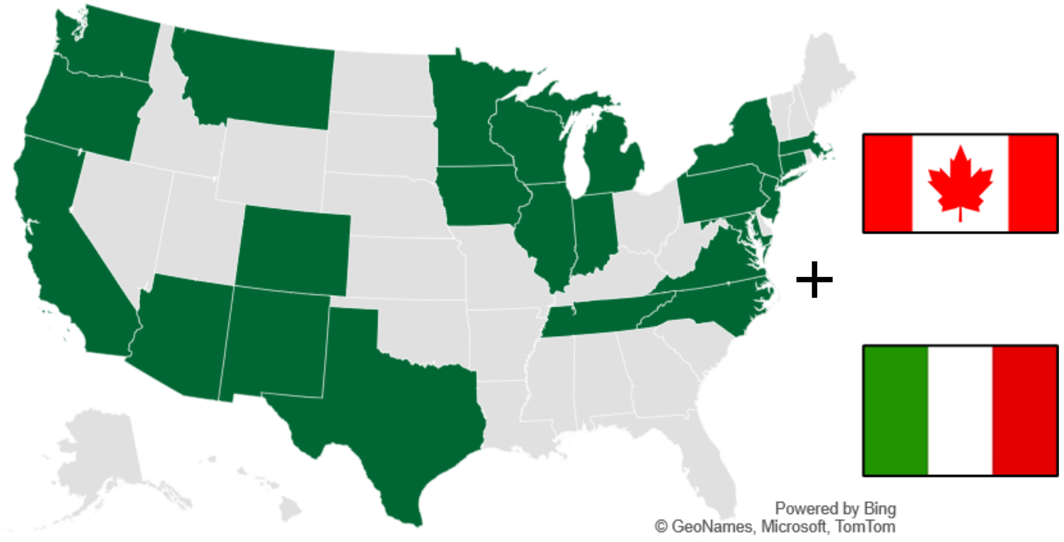
39 Academic institutions + 11 DOE Labs + 14 Companies + 3 Other agency entities + 2 Foreign institutions =

69 Institutions from 23 states + DC + Canada + Italy

Members of QED-C, connections to NSF Quantum Leap Challenge Institutes (e.g. Jun Ye in LBNL-led Center)

Unique approaches for workforce development and industry outreach (e.g. Simons Institute, pilot programs)

Leveraging other DOE investments (e.g. Testbeds, JCESR)



DOE-SC National QIS Research Centers are a critical part of our QIS Portfolio

Whole of SC & Whole of QIS
- DOE team approach in preparation of the solicitation (FOA)
- Cross-program coordination of QIS within SC
- SC-wide and QIS-wide scope, management, and expected impacts

Community Engagement
- RFI as a prelude to the FOA
- New SC web-site: https://science.osti.gov/Initiatives/QIS
- Stewardship role

Coordination & Partnerships
- Facilitate participation by different types of institutions by flexible arrangements
- Focus on all levels of the S&T innovation chain

Long-term Science Challenges
- **QIS S&T Innovation Chain**
  - Technical Areas of Interest
- **QIS Ecosystem Stewardship**
  - Management Structure
  - Instrumentation and Facilities

QIS Coordination within Office of Science

All Committees and Working Groups Membership Crosses SC

SC QIS Committee
Lead: Ceren Susut

National QIS Research Centers WG
Lead: Ceren Susut

QIS Core Research WG
Lead: Tom Russell

QIS Meetings WG
Lead: Claire Cramer

National QIS Research Centers' Executive Council
Chair: David Awschalom

Center synopses and links at science.osti.gov/Initiatives/QIS