The Quantum Benchmarking Initiative (QBI)

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QBI Motivation – Separating Hype from Reality

Economic Opportunity

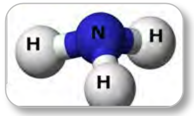
- It has been **credibly hypothesized** – but not proven – that quantum computers would have a **transformational impact** on many industries.
- **Examples:** Machine learning, quantum chemistry, materials discovery, molecular simulation, many-body physics, classification, nonlinear dynamics, supply chain optimization, drug discovery, battery catalysis, genomic analysis, fluid dynamics, protein structure prediction, solving systems of linear and nonlinear equations.

Pharmaceuticals
($145B Market)

Image Recognition
($109B Market)

Battery Catalysis
($141B Market)

Machine Learning
($97B Market)



Nitrogen Fixation
($85B Market)

Encryption
($146B Market)

Sources: Shutterstock

Security Threat

- **NIST analysis of the threat:**
  "If large-scale quantum computers are ever built, they will be able to break many of the public-key cryptosystems currently in use. This would ***seriously compromise*** *the confidentiality and integrity of digital communications on the Internet and elsewhere."*
- **NIST on the timeline for cryptographically relevant quantum computers:**
  "Some engineers even predict that ***within the next twenty or so years*** *sufficiently large quantum computers will be built to break essentially all public key schemes currently in use."*

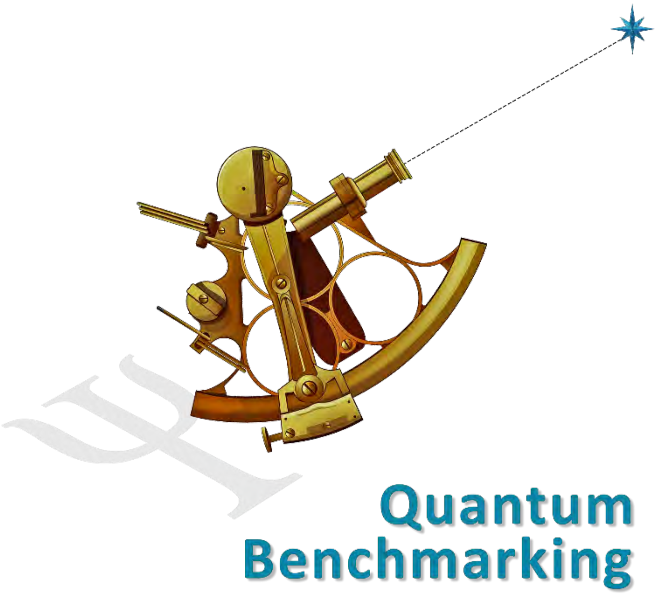
Source: Shutterstock

If the hype is real, utility-scale quantum computers have the potential for significant economic disruption

[Quotes from: *https://csrc.nist.gov/projects/post-quantum-cryptography]*

What Questions Are We Trying to Answer in QBI?

QBI expands upon work done in two DARPA programs – they were designed to answer these questions:



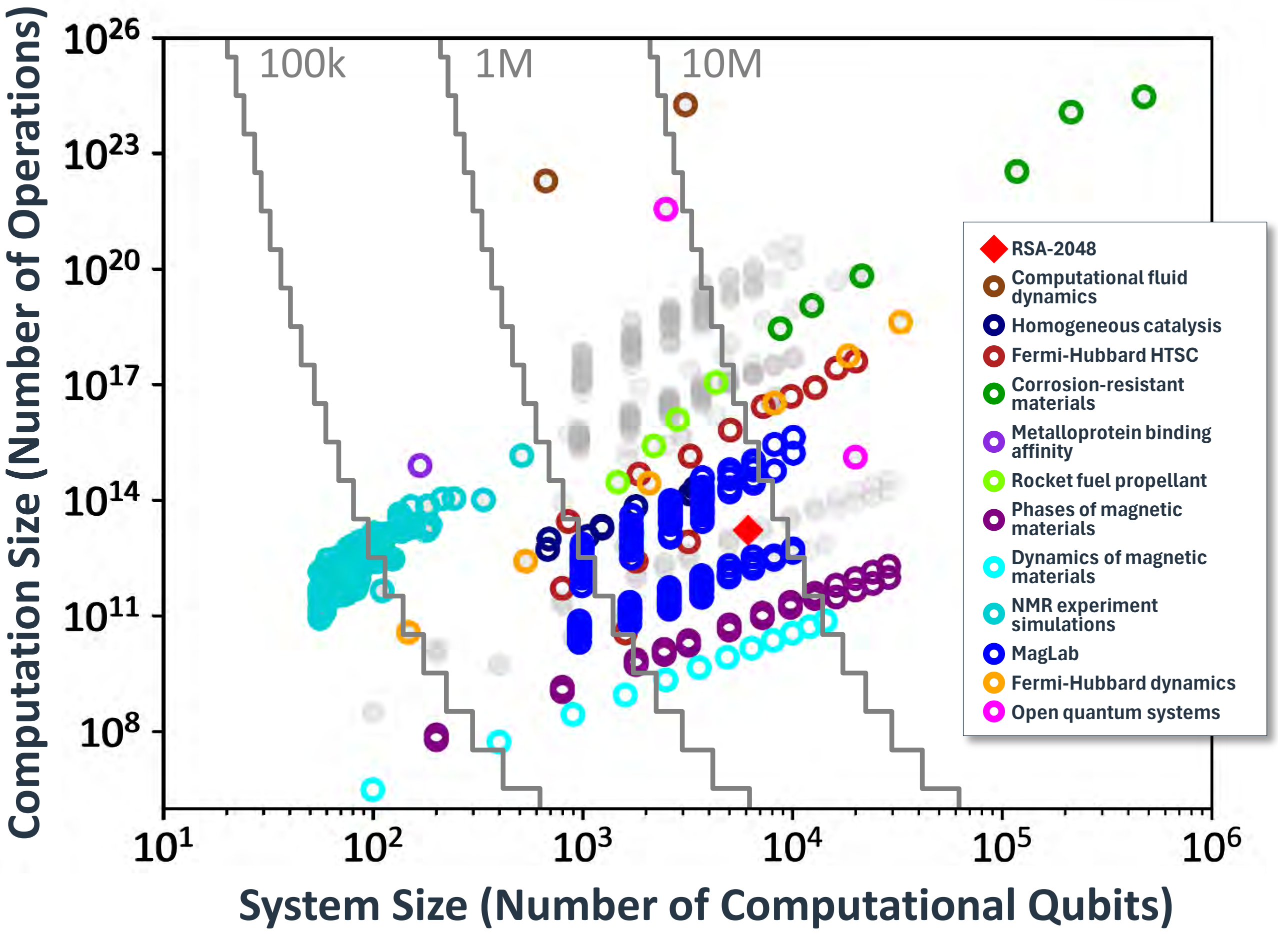
Would a very powerful quantum computer be industrially useful?

Can efforts to build a very powerful quantum computer in the near term succeed?

Preliminary Results from the Quantum Benchmarking Program

Applications that could benefit from a quantum coprocessor:

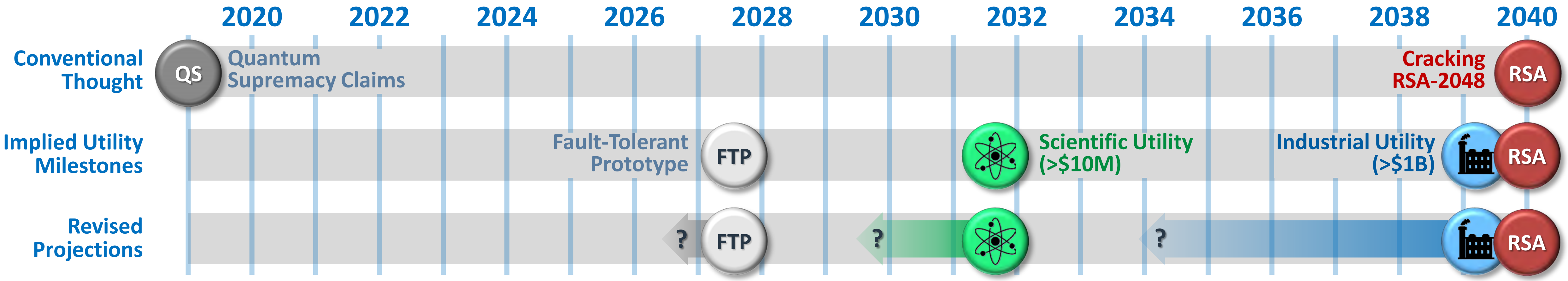
- Simulating correlated materials
- Developing corrosion resistant materials
- Developing new rocket fuels and explosive materials
- Dynamical simulations (for new solar cells, better understanding of biological processes, and magnetic materials)
- New methods to compile algorithms to fault-tolerant quantum architectures

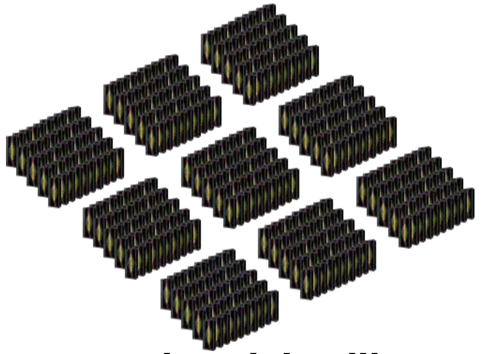


Grey solid circles represent pessimistic resource estimates. Colored circles are optimistic resource estimates based on known improvements. All points supported by detailed published pre-prints.

Preliminary evidence suggests that large-scale quantum computers could be industrially useful

What About Hardware?





Fault-Tolerant Prototype	**Scientific Utility**	**Industrial Utility**	**RSA-2048**
Small fault-tolerant quantum computer demonstrating utility-scale viability	Moderate-sized physics models of materials, e.g., Fermi-Hubbard	Larger-size quantum chemistry, e.g., catalysis	Gidney-Ekera's solution to RSA-2048 public-key cryptosystem

Is it plausible that industrial quantum computers will be developed within a decade?

The primary goal of the Quantum Benchmarking Initiative (QBI) is to determine if any approach to quantum computing can achieve utility-scale operation by the year 2033

Stages of QBI

QBI Stage A: Plausibility	QBI Stage B: R&D Plan	QBI Stage C: Validation and Co-Design
6-months Up to $1M*	12-months Up to $15M*	Duration tailored to performer Up to $300M*

Stage A

- Will focus on the performer's utility-scale quantum computer (USQC) concept

Stage B

- Will focus on examining the performer's baseline research and development (R&D) plan

Stage C

- Will determine if a USQC can be constructed as designed and operated as intended

QBI will focus on verifying and validating the path to utility-scale quantum computers, and will not focus on tracking incremental improvements to the state of the art

**see the QBI Program Solicitation for details and conditions*

DARPA

QBI Stage C Teams (from US2QC Pilot Program)

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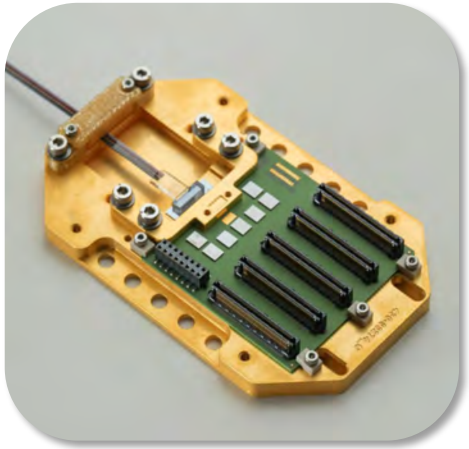
PsiQuantum

Core Technology

- Integrated photonics
- Measurement-based
- Employs a lattice-like fabric of photonic qubits



Source: PsiQuantum

Source: PsiQuantum

Microsoft

Core Technology

- Solid state
- Measurement-based
- Qubits based on exotic excitations of a novel, engineered state of matter

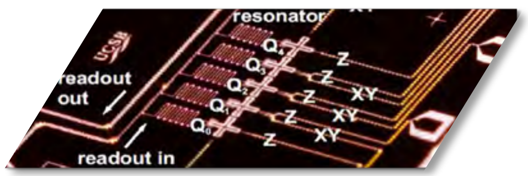
Source: Microsoft

Source: Microsoft

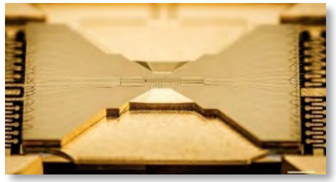
Conventional wisdom held that neither of these two performers had a serious chance of success

New QBI Stage A Teams

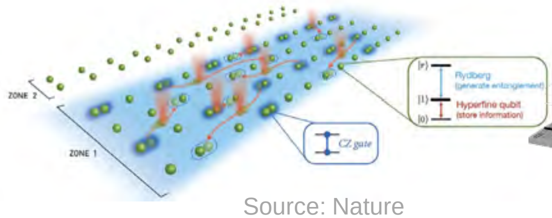
Superconductors	Ions	Neutral Atoms	Semiconductors/ Spins	Photons



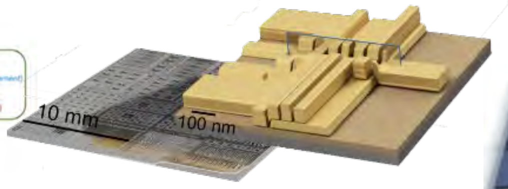
Source: Nature



Source: IonQ



Source: Nature



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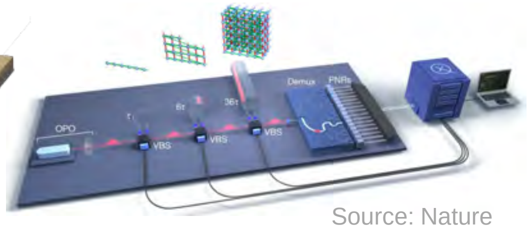


Source: Nature

Superconductors:
Atlantic Quantum
IBM
Nord Quantique
Alice and Bob
HPE
Rigetti

Ions:
IonQ
Oxford Ionics
Quantinuum

Neutral Atoms:
Atom Computing
QuEra

Semiconductors/Spins:
Diraq
Silicon QC
Quantum Motion

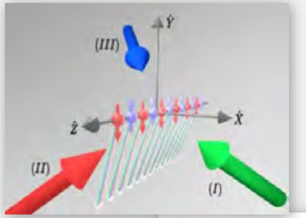
Photons:
Xanadu

Photonic

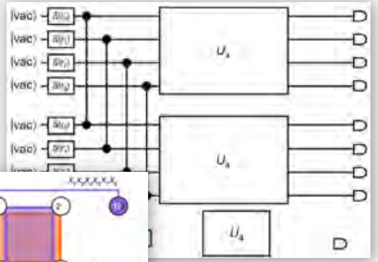
The new teams demonstrate significant potential for strategic surprise

Stage A Test and Evaluation (T&E) Approach

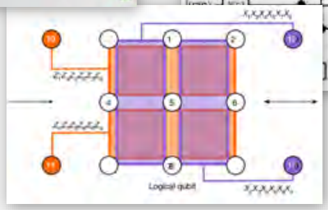
Deep, Targeted Analysis
(Physics teams)



Source: PhysRev-Research



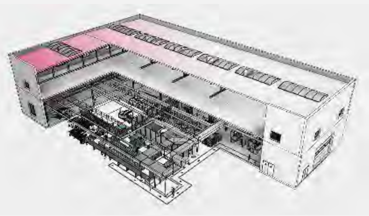
Source: Nature



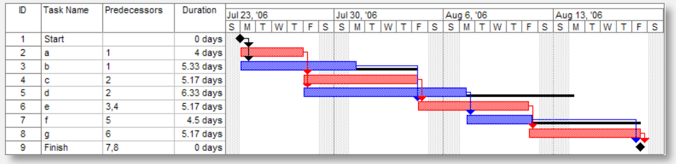
Source: Nature

Broad System Evaluation
(Systems Engineering teams)

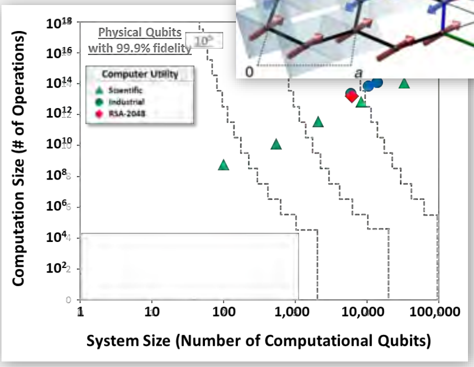
Source: Shutterstock

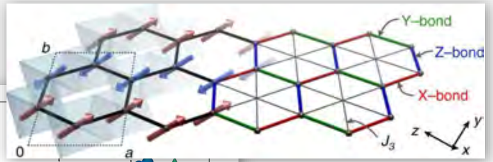


Source: Autodesk



Utility Estimation
(Applications teams)





Source: Los Alamos National Laboratory

Stage A System Evaluation Methodology

Roots (3)

USQC Physical Decomposition

- What is a high-level description of a Utility Scale Quantum Computer?
- What are all the components and sub-systems and how do they fit together?
- What happens at the interfaces of those components and sub-systems?

USQC Functional Decomposition

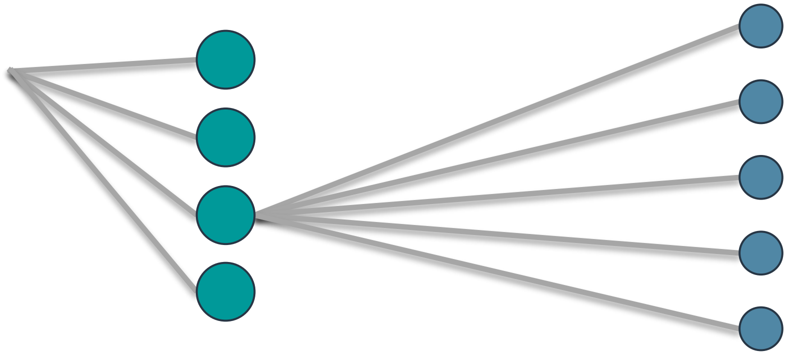
- How does the proposed USQC actually work?
- How is it intended to be used?
- What are its intended modes of operation and user interfaces?

Performer Processes

- What processes, plans, and products does this team have in place?
- How have they leveraged those (or different) processes, plans, products, in the past to come to their current USQC concept?
- How will the team's processes, plans, products change or be leveraged in the future to burn down all the risks and actually be ready to start USQC construction?

Branches (16)

Leaves (50)



Example Branch
Components and Subsystems

Example Leaf
System description of the USQC including a graphic depiction of the components and subsystems

System Evaluation → Provide a broad evaluation of the completeness and quality of concepts

Stage A System Evaluation (Generic Example)

Performer Processes

System Concept	1.1.1	Qubit Modality/Platform	Meets
System Concept	1.1.2	Key Features	Meets
Prototypes/ Systems	1.2.1	Prototypes/Metrics	Partially Meets
Prototypes/ Systems	1.2.2	Tests & Prototypes	Partially Meets
Design Processes	1.3.1	Design Methods	Meets
Design Processes	1.3.2	Ability to Design/Build	Partially Meets
R&D Plan	1.4.1	R&D Plan Description	Meets
R&D Plan	1.4.2	Program Timelines	Meets
R&D Plan	1.4.3	Business Case	Partially Meets
Critical Technologies & Risks	1.5.1	Critical Technologies	Meets
Critical Technologies & Risks	1.5.2	Technical Risks	Partially Meets
Critical Technologies & Risks	1.5.3	Programmatic Risks	Partially Meets
Trade Studies	1.6.1	Process & Approach	Meets
Trade Studies	1.6.2	Trade Study Status	Partially Meets
Supply Chain Analysis	1.7.1	External Supply Chains	Meets
Supply Chain Analysis	1.7.2	Internal Production Capability	Meets
Supply Chain Analysis	1.7.3	Long-lead Components	Partially Meets
Cost Analysis	1.8.1	R&D Plan Cost	Meets
Cost Analysis	1.8.2	Design/Construction	Meets
Cost Analysis	1.8.3	Lifetime/Operating	Meets

Physical Decomposition

Subsystems & Components	2.1.1	System Description	Meets
Subsystems & Components	2.1.2	Design Plan/Timeline	Meets
Subsystems & Components	2.1.3	Facility Needs	Partially Meets
Subsystems & Components	2.1.4	Infrastructure Security	Meets
Physical Quantum Layer	2.2.1	Qubit Description	Meets
Physical Quantum Layer	2.2.2	Qubit Number	Meets
Physical Quantum Layer	2.2.3	Qubit Connectivity	Partially Meets
Physical Quantum Layer	2.2.4	Quantum Operations	Partially Meets
Classical Computing	2.3.1	Classical Architecture	Meets
Classical Computing	2.3.2	Logic Flow	Meets
Classical Computing	2.3.3	Total Resources	Meets
Interfaces & Connectivity	2.4.1	Internal Interfaces	Meets
Interfaces & Connectivity	2.4.2	External Interfaces	Partially Meets
Interfaces & Connectivity	2.4.3	User Interactions	Meets
Noise Models	2.5.1	Noise Sources	Partially Meets
Noise Models	2.5.2	Noise Impacts	Does not Meet
Fault Tolerance	2.6.1	Encoding Protocols	Meets
Fault Tolerance	2.6.2	Implementation	Meets
Fault Tolerance	2.6.3	Error Models	Meets

Functional Decomposition

Architecture & Metrics	3.1.1	Functional Decomposition	Meets
Architecture & Metrics	3.1.2	Architecture Description	Meets
Architecture & Metrics	3.1.3	Logical Qubits	Meets
Programming & Compiling	3.2.1	High-Level Commands	Exceeds
Programming & Compiling	3.2.2	Readout Approach	Meets
Programming & Compiling	3.2.3	Execution Procedures	Exceeds
Modes of Operation	3.3.1	Mode Description	Meets
Modes of Operation	3.3.2	Operating Concept	Meets
Modes of Operation	3.3.3	Calibration Process	Does not Meet
Modes of Operation	3.3.4	Runtime Model	Partially Meets
Modes of Operation	3.3.5	Boot Sequence	Partially Meets
Applications	3.4.1	Utility-Scale Applications	Meets
Applications	3.4.2	Execution Cost	Partially Meets
Applications	3.4.3	Application Metrics	Meets
Algorithms	3.5.1	Algorithms & Implementation	Greatly Exceeds
Algorithms	3.5.2	Inputs & Outputs	Exceeds
Algorithms	3.5.3	Quantum/Classical Integration	Exceeds
Algorithms	3.5.4	Quantum Programs	Meets
Software	3.6.1	Operating Software	Partially Meets
Software	3.6.2	Development Software	Meets

Criteria
- Greatly Exceeds
- Exceeds
- Meets
- Partially Meets
- Does not Meet

QBI Key Partners

QBI has built the worlds-largest quantum computer test and evaluation team

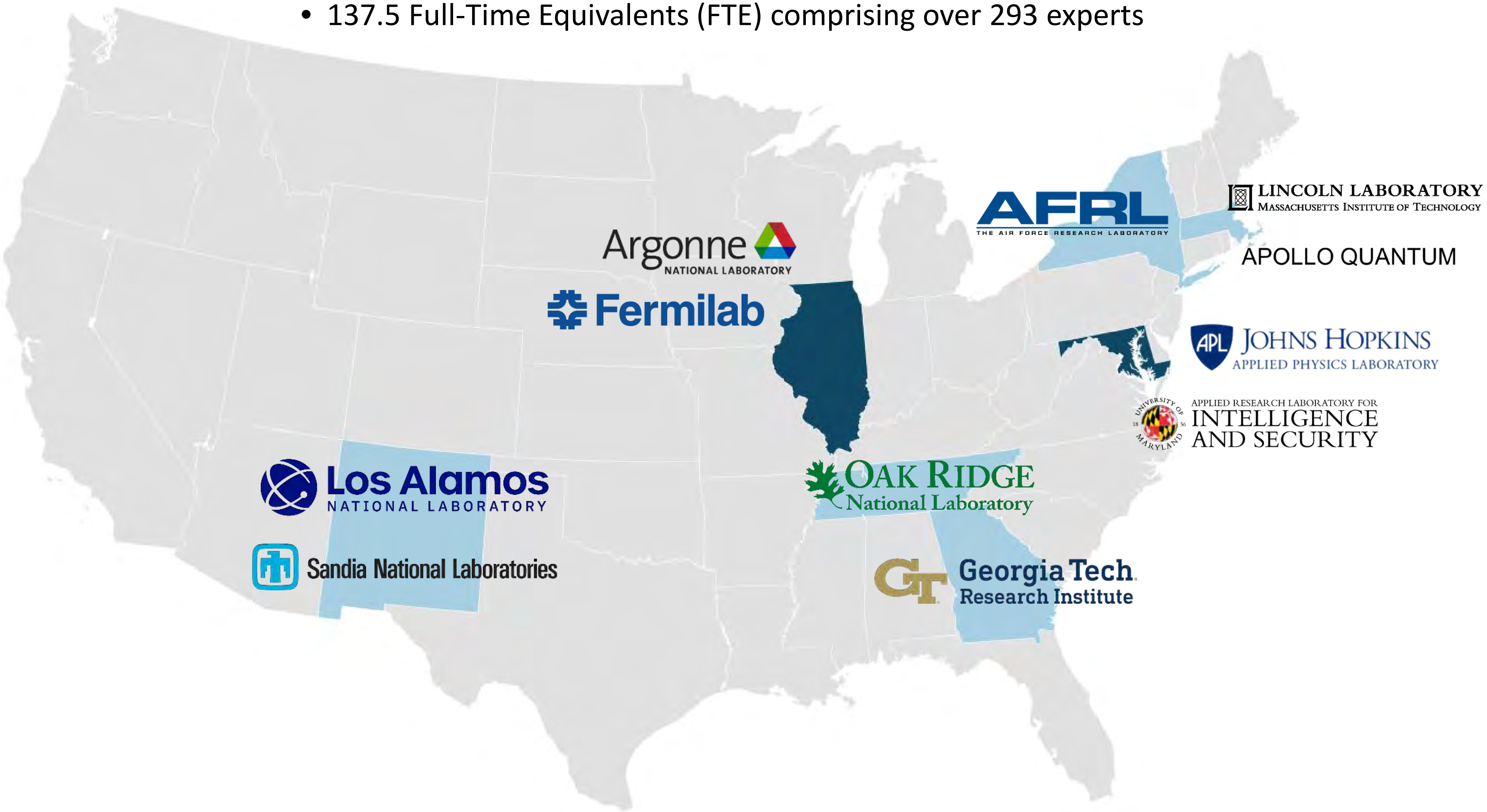
- 11 organizations, plus DARPA
- 137.5 Full-Time Equivalents (FTE) comprising over 293 experts

Partner Organizations

Department of Energy

State of Illinois

State of Maryland



How Can I Get Involved?

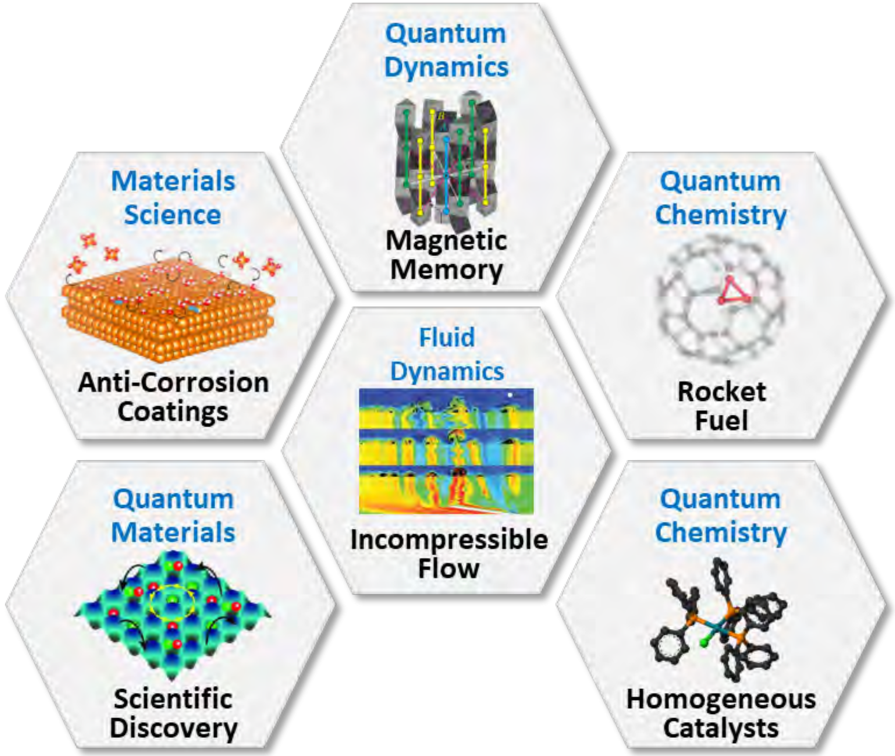
- It is possible that new on-ramps for companies to join QBI will be available in the future
  - Watch for any opportunities to be announced on https://www.darpa.mil/work-with-us/opportunities

- The QBI Test & Evaluation team can use new talent
  - DARPA is expanding the best quantum computing Test and Evaluation team in the world
  - We are looking for individuals and organizations to help evaluate utility-scale quantum computing concepts, plans, and devices

- **DARPA is always looking for new Program Managers!**

If We Succeed, What Difference Will It Make?

Source: Shutterstock



National Security Impact

Reduce Strategic Surprise

Economic Impact

Reveal First Utility-Scale Quantum Computers

www.darpa.mil