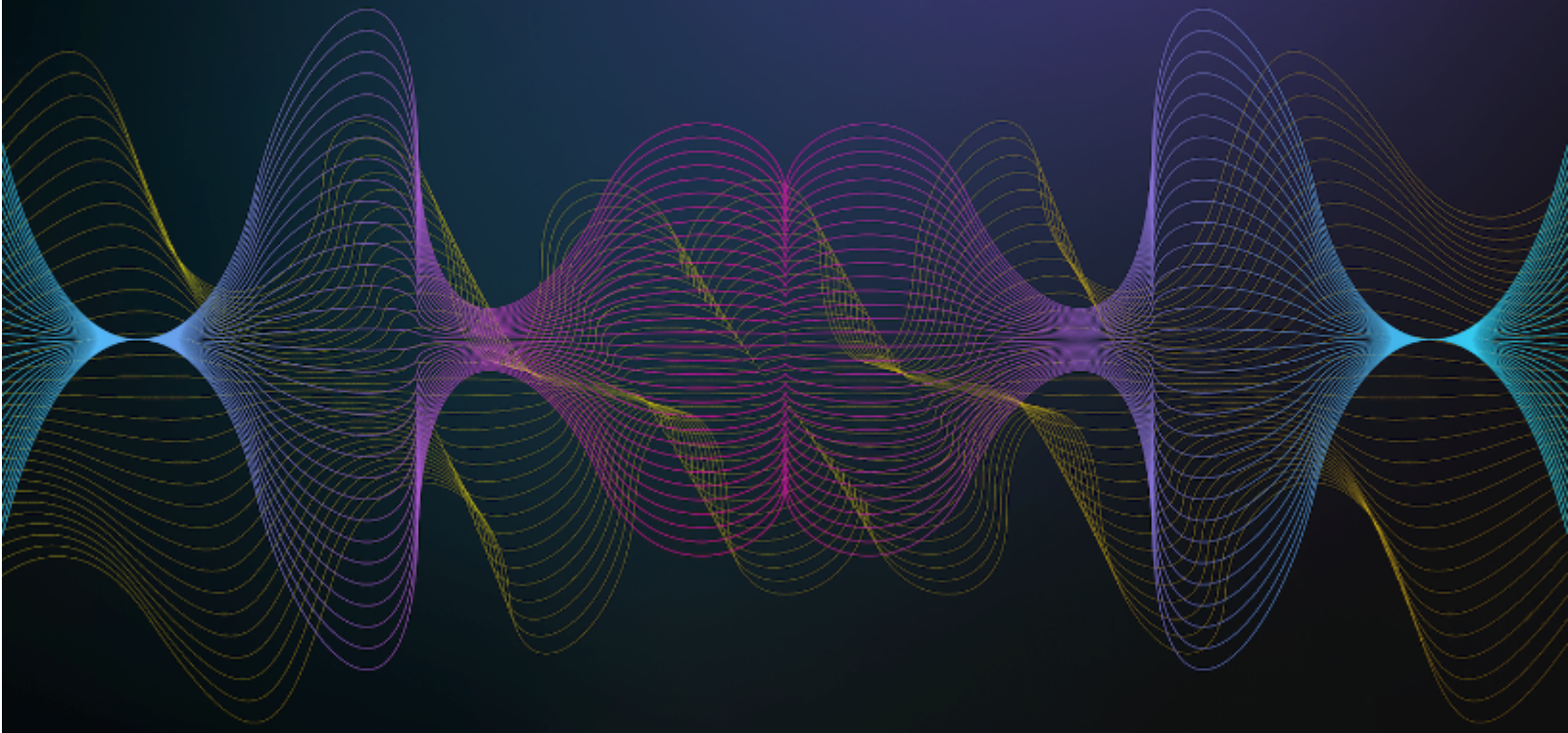
Chattanooga Quantum Collaborative Study

Laying the groundwork for Chattanooga Quantum Collaborative's vision to lead a regional center of quantum excellence



Chattanooga Quantum Collaborative | RESONANCE | THE QUANTUM INSIDER

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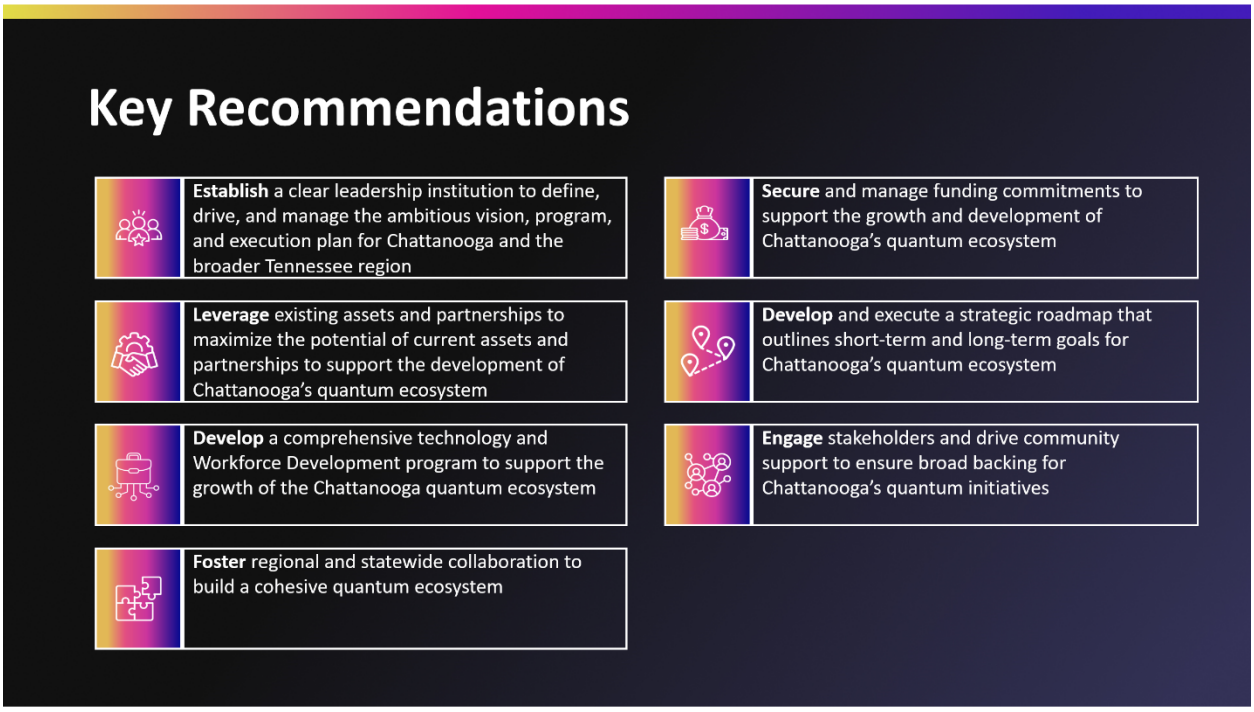
Executive Summary

This report provides an analysis of the current landscape and future potential for quantum technology in Tennessee. Commissioned by the Chattanooga Quantum Collaborative (CQC), and delivered in partnership with Resonance, the report was completed over the course of Q2 and Q3 2024. This report leverages existing datasets from The Quantum Insider and other regional open data sources and has been enriched with 18 interviews with key stakeholders undertaken through a combination of in person and virtual meetings.

The assessment of the existing quantum technology ecosystem reveals a compelling mix of work, initiatives and organizations across academia, research centers, and end users. It also identifies promising applications for quantum technology in Tennessee based on the state's existing industrial strengths and strategic priorities.

The report also synthesizes relevant national and global studies to provide context on other regional strategies. It highlights best practices and lessons learned from successful quantum initiatives worldwide, focusing on commercialization, infrastructure advancement, and workforce development.



A high-level SWOT analysis identifies key strengths, weaknesses, opportunities, and threats within the regional quantum ecosystem. This initial analysis sets the stage for future more detailed assessment with additional research and stakeholder validation. Finally, the report concludes with a focused set of recommendations.

In addition to this report, the Chattanooga Quantum Collaborative was provided with a database of quantum ecosystem assets, as well as more detailed specific recommendations on the potential shape of a future quantum program in the region.

The findings and recommendations presented in this report provide an important step in building a strategic roadmap for Tennessee's quantum technology ambitions.

Tennessee Quantum Ecosystem

Overview

Located in the southeastern US, Tennessee is home to approximately seven million people, making it the 15th largest state in the country by population. Tennessee's culture, geography, and economy are distinct in each of the state's three regions - Middle Tennessee, Eastern Tennessee, and West Tennessee. Local partnerships between universities and industries located within the same region have historically been the most prevalent, such as the partnerships between Clarksville companies and the University of Memphis in Western Tennessee, or between Chattanooga companies and the University of Tennessee Chattanooga.

Tennessee's largest cities - Nashville, Memphis, Knoxville, Chattanooga, and Clarksville – are profiled below in further detail:

- **Nashville**: The state capital and its largest city, Nashville anchors the Tennessee economy with a range of institutions and enterprises operating across the healthcare, higher education, state government, and private industrial sectors. The city is renowned for its music and cultural attractions which attracted a state-leading $10 billion in tourism revenue in 2022[1]. Nashville's largest industry is healthcare – it is home to over 300 health care companies including the Hospital Corporation of America, the largest private operator of hospitals in the world. It is also home to Vanderbilt University, in addition to a range of other private HBCUs, state colleges, and regional institutions.

- **Memphis** The westernmost major city in Tennessee, Memphis plays a pivotal role nationally in the transportation and logistics industry, acting as the global headquarters for FedEx and bolstering the local economy through its robust manufacturing and healthcare sectors. As the home to FedEx, Memphis acts as an exchange point for packages and / or containers moving within the continental US between the eastern, western, northern, and southern quadrants. Memphis is also soon to be home to the world's largest supercomputer, xAI[2], which will power Musk's own companies but also has the potential to make Memphis and the broader Western Tennessee region a meaningful hub for computing.

[1] *Research | Tennessee Vacation Industry*. https://industry.tnvacation.com/industry/research.
[2] Morris, Chris. "Elon Musk Selects Memphis for xAI's Supercomputer Site." *Fortune*, https://fortune.com/2024/06/18/elon-musk-xai-memphis-supercomputer-site.

- **Chattanooga** is one of the two largest cities in the Eastern Tennessee region along with Knoxville. Located in Southeastern Tennessee and bisected by the Tennessee River, Chattanooga sits along Tennessee's border with Alabama and Georgia. Chattanooga is home to the University of Tennessee at Chattanooga (UTC), one of the largest institutions in the University of Tennessee System. The Chattanooga Electric Power Board (EPB) plays a crucial role in Tennessee's economy, providing gigabit internet infrastructure to foster significant tech innovation and attract a growing number of start-ups. Additionally, the city is emerging as a local quantum hub, driving advancements in quantum technology, and positioning itself as a home to leaders in cutting-edge technologies. The city has also seen growth in its manufacturing sector since Volkswagen established its Chattanooga assembly plant in the city in 2011.

- **Knoxville** houses a strong manufacturing base and is also home to the University of Tennessee, Knoxville. It is the state's third largest city and as such it serves as the operational headquarters for the Tennessee Valley Authority, as well as the legislative headquarters for the Eastern Tennessee governing body. Oak Ridge National Labs are also located a short distance from Knoxville (<30-minute drive).

- **Clarksville** houses a rapidly growing population with local economic activities centered around manufacturing, a significant military presence at Fort Campbell, and education via Austin Peay State University. As a Middle Tennessee city, Clarksville is a secondary logistics hub, supporting Memphis with a FedEx distribution center in addition to an Amazon warehouse & distribution center. Taken together with Murfreesboro and Franklin, Clarksville is one of the three smaller metropolitan satellite cities surrounding Nashville.

The state has a mature and well-resourced manufacturing ecosystem that caters to sectors such as automotive, energy, aerospace, chemicals, and biotech. As such Tennessee attracts large companies not only from headquarters in other states but also from across the globe to set up manufacturing divisions within its borders. Tennessee has a vibrant industrial sector, with key players like Nissan, Bridgestone, and Eastman Chemical Company establishing major operations in the state. These companies not only benefit from the existing industrial infrastructure but also drive innovation and technological advancement within their respective fields.

University of Tennessee Knoxville, University of Tennessee Chattanooga, and Vanderbilt University are well-resourced and equipped with facilities and education programs to support high-caliber students. Moreover, Tennessee Tech University, Chattanooga State Community College, and the University of Memphis are also contributing to the state's strong educational foundation, providing a pipeline of skilled graduates ready to enter various high-tech industries, and ensuring that many of the relevant resources required to build a vibrant quantum ecosystem are in place.

The state is home to Oak Ridge National Laboratory, a world leader in advanced scientific research and has demonstrated a keen interest in exploring experimental technologies (including quantum) for various use cases. It is also home to research centers and government laboratories that are at the forefront of technological innovation. The Institute for Advanced Composites Manufacturing Innovation (IACMI) and the Manufacturing Demonstration Facility (MDF) at Oak Ridge National Laboratory are examples of facilities that support innovative research and development.

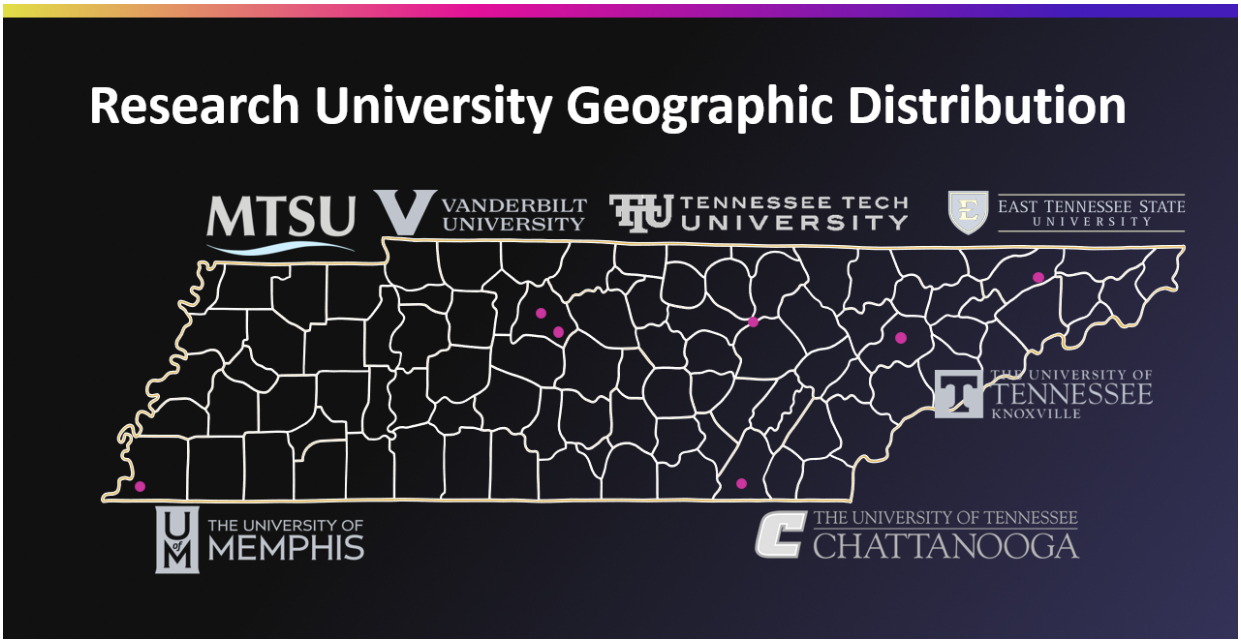
The following section of the report inventories and analyzes the existing assets within Tennessee with direct relevance to the state's emergent quantum ecosystem. The goal of this exercise is to emphasize that Tennessee's quantum ecosystem is already partly formed, and that growing it effectively will depend on leveraging and combining existing assets.

The inventory is divided into academia - encompassing research-intensive universities as well as community colleges, private colleges, and other tertiary educational institutions - quantum companies, relevant industry participants, research centers, government laboratories, and investors. The study also considers the importance of public utilities in Tennessee for purposes of large-scale investment in key state initiatives.

Academic Institutions

Research universities

Tennessee has a total of 24 public postsecondary academic institutions[3] and 43 private postsecondary academic institutions[4]. Of these, The University of Tennessee Knoxville (UTK), Tennessee Tech, The University of Tennessee Chattanooga (UTC), Middle Tennessee State University (MTSU), Eastern Tennessee State University (ETSU), and Vanderbilt account for most quantum-relevant research activity in the state.[5]



A deep dive into research at these universities shows a total of 13 academic research groups, centers, and initiatives whose core objective is to research quantum technologies, and an additional 37 groups, centers, and initiatives researching quantum-

[3] National Center for Education Statistics (NCES), *https://nces.ed.gov/collegenavigator/?s=TN&l=92+93+94&ct=1&ic=1+2+3*. Note: When certificate-granting institutions are included, the count (24) increases to 47. However, given that the majority of certificate-granting institutions (as opposed to Bachelors, Associates, or Advanced Degree institutions) are pre-professional programs, such as cosmetology or medical technician certification programs, they have not been counted in the report but are noted here for reference.

[4] National Center for Education Statistics (NCES), *https://nces.ed.gov/collegenavigator/?s=TN&l=92+93+94&ct=2&ic=1+2+3*. Note: When certificate-granting and private for-profit institutions are included, the count (43) increases to 95. However, for the same reasons as above they have not been counted in the report but are noted here for reference.

[5] *Tennessee's Colleges and Universities*. https://www.tn.gov/thec/learn-about/tennessee-s-colleges-and-universities.html

adjacent technologies. These groups have been profiled because they have the potential to be integrated into a broader quantum ecosystem story.

These universities also host a significant infrastructure footprint for applied sciences, typically in the form of research centers. This infrastructure is discussed in-depth in the research centers and government section of the report.

University of Tennessee (UT) System

The University of Tennessee System (UT system) is a system of public research universities renowned for its emphasis on engineering, science, and technology, offering a broad range of academic programs in each area. The UT System operates across the state of Tennessee and consists of four campuses - University of Tennessee, Knoxville, UT Chattanooga, UT Southern, and UT Martin – in addition to one health science center. It is governed by a UT System president along with a board of 12 trustees responsible for overseeing UT system campuses.

The UT System has demonstrated its interest in quantum technologies through past partnerships with Oak Ridge National Laboratories, the Tennessee government, and other state industries to host initiatives aimed at advancing quantum information science. UT system schools also offer a range of undergraduate and graduate courses focused on quantum-adjacent academic fields, primarily in the departments of physics, computer science, and electrical engineering.[6]

The University of Tennessee Chattanooga (UTC)

The University of Tennessee Chattanooga (UTC) is a UT System campus dedicated to undergraduate and graduate instruction in Chattanooga and the surrounding areas. Founded in 1866, UTC joined the UT System in 1969, expanding its student body to ~11,500 undergraduate and graduate students, and increasing its academic offerings to include business, engineering, arts & sciences, health professions, and nursing.

Under Dr. Reinhold Mann and Dr. Tian Li's leadership, UTC launched the Quantum Initiative in 2022[7] to deliver educational and workforce training opportunities enabled by quantum technology. The project received initial funding of $3 million over three years supporting infrastructure development. A community project will provide an additional $3.5 million over four years, aiming for sustainability. The initiative aims to foster new partnerships across the region, and to expand UTC's capacity for R&D in quantum

[6] See "Figure 4" for examples
[7] "UTC Quantum Initiative." UTC, https://www.utc.edu/research/utc-quantum-initiative.

information sciences and was broadly catalyzed by the development of the EPB quantum network.

> *"The launch of a quantum initiative here was triggered by EPB deploying the first phase of their commercial network, discussing that with the chancellor and offering that we would have an access node on campus." - UTC Researcher*

Dr. Li is leading quantum networking and communications research efforts in the UTC Quantum Node Lab. His course covers this specialty but will also evolve to better reflect quantum information science and include quantum communication in addition to quantum computation. UTC plans to offer a minor in quantum information science and engineering, a computational sciences PhD program concentration in quantum computing, and a certificate program in quantum information science.

> *"A critical aspect of the initiative is to integrate quantum studies into undergraduate and graduate curriculums, impacting student enrollment and education." - UTC Researcher*

University of Tennessee Knoxville (UTK)

The University of Tennessee Knoxville is the flagship campus of the UT system. Beyond the physics department, the university has several interdisciplinary research centers, as well as facilities for device fabrication and materials testing with a focus on photonic and electronic technologies with participation from UTK's electrical and computing engineering faculty Concentrations in communication and networking, applied AI, high-performance computing (HPC), and computing for energy (such as grid management and simulation) are currently offered at UTK.

The University of Tennessee recently developed the UT Research Enterprise, an initiative that aims to enhance research output and ensure emergent fields are represented. The initiative encompasses a broad array of research activities and collaborations aimed at addressing complex, interdisciplinary challenges. UT reported ~$340 million in research

expenditures and ~$430 million in sponsored projects for the fiscal year in 2023,[8] highlighting the significant amount of funding that the UT Research Enterprise is deploying locally.

UT Research Enterprise's research initiatives span multiple campuses and involve partnerships with prominent institutions and industries. Collaborations with key partners such as Oak Ridge National Laboratory have integrated UTK into advanced manufacturing research initiatives, most notably through the Institute for Advanced Composites Manufacturing Innovation (IACMI), a $259 million public-private partnership focused on advanced materials research.[9] The IACMI The UT Research Enterprise also emphasizes multidisciplinary research through various centers and institutes, such as the Institute for Advanced Materials and Manufacturing (IAMM) and the Center for Renewable Carbon (these centers focus on cutting-edge research areas, including advanced materials, renewable energy, and sustainability).

The University of Tennessee, Knoxville, hosts the Center for Advanced Materials and Manufacturing (CAMM), a cutting-edge research initiative supported by the National Science Foundation (NSF) with a focus on quantum materials. CAMM is led by Dr. Adrian Del Maestro, chair of the Physics and Astronomy Department at UTK, a specialist in quantum phase transitions, entanglement, and fluid dynamics. The center also benefits from the leadership of Dr. Steve Zinkle, Governor's Chair Professor of Nuclear Physics, who holds a Ph.D. in nuclear engineering and has a joint appointment with Oak Ridge National Laboratory. Additionally, Dr. Alan Tennant, a leading expert in condensed matter physics and quantum magnetism and professor in UTK's Department of Physics and Astronomy, brings further depth to the initiative.

Vanderbilt University

Located in the heart of Nashville, Vanderbilt University is a private research university offering a mix of academic programs, from liberal arts to professional studies. It is known for its historic campus and commitment to research excellence and is a cornerstone institution in the region.

[8] Amos, Adria. "UT Research Breaking Records, Growing Impact in Tennessee and Beyond." Research, Innovation & Economic Development, 31 Jan. 2024, https://research.utk.edu/oried/2024/01/31/ut-research-breaking-records-growing-impact-in-tennessee-and-beyond/.
[9] Jay, Hannah. "IACMI Composites Initiative Launched." *IACMI*, 18 June 2015, https://iacmi.org/composite-manufacturing-initiative-launched/.

In 2023, Vanderbilt University unveiled its collaboration with the IBM Quantum Hub,[10] granting access to IBM's quantum computing systems for both its academic community and industrial partners. Spearheaded by the Department of Computer Science and Engineering, Vanderbilt is facilitating access to the quantum hub while jointly developing quantum computing courses in partnership with the departments of mathematics and physics. Vanderbilt recently launched an 8-month long course in quantum computing (Wond'ry Quantum Studio)[11] which introduces participants to the foundational principles of quantum computing and further building a quantum community locally.

There is research activity at Vanderbilt in areas such as environmental monitoring, quantum sensing, and biomedical applications. The Vanderbilt Institute in Surgery and Engineering received a $500,000 grant through the National Science Foundation's Innovation Corps (I-Corps) program[12] to help medical researchers commercialize their products. Principal Investigators working at Vanderbilt have been awarded additional $50,000 I-Corps grants in subsequent years to commercialize medical products including minimally invasive surgical tools, data imaging software, and robotic capsule devices.

Vanderbilt's physics faculty is known for its work on condensed matter physics and quantum materials, evidenced most clearly in the Vanderbilt University Institute of Nanoscale Science and Engineering (VINSE). Although the VINSE does not work on quantum technologies nominally, it works on precursor fields where research advancements must be made for quantum technology to become commercially viable, such as cleanroom facilities for nanofabrication and advanced microscopy tools. Advancements at VINSE have the potential to become both highly desirable and highly lucrative for quantum device manufacturers globally.

The university also fosters centers and institutes for interdisciplinary and applied research in fields such as biosystems research (Vanderbilt Institute for Integrative Biosystems Research and Education), medical imaging (Vanderbilt Institute of Imaging Science) and biochemical research (Vanderbilt Institute of Chemical Biology).

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[10] "Quantum Design Studio." *Vanderbilt University*, https://www.vanderbilt.edu/the-wondry/quantum-studio/.
[11] "Wond'ry Quantum Studio Introduces New Course for Quantum Computing Enthusiasts." *Vanderbilt University*, https://news.vanderbilt.edu/2023/08/14/wondry-quantum-studio-introduces-new-course-for-quantum-computing-enthusiasts/.
[12] "The Wond'ry Lands $500K I-Corps Site Grant, Ramps up Efforts to Launch Start-Ups." *Vanderbilt University*, https://news.vanderbilt.edu/2017/09/01/the-wondry-lands-500k-i-corps-site-grant-ramps-up-efforts-to-launch-start-ups/.

Other universities

Middle Tennessee State University

Middle Tennessee State University is home to the Quantum Science Initiative (QSInitiative), which focuses on advancing research, education, and outreach in quantum information science (QIS) by integrating quantum concepts into existing courses, developing new educational programs, and fostering partnerships with regional universities. Key research areas include quantum materials and quantum computing.

Eastern Tennessee State University

Eastern Tennessee State University (ETSU) is renowned for its strong focus on STEM education and interdisciplinary research. ETSU's initiatives typically involve collaborations across various scientific disciplines, which includes quantum-adjacent activity in computational science and advanced materials.

The ETSU computer science department recently launched the ETSU Cybersecurity and Network Infrastructure program to establish itself as a statewide leader in cybersecurity education and job training. Additionally, the physics department at ETSU established a concentration in quantum physics, offered in close partnership with the computer science department. ETSU exemplifies the opportunity to grow existing academic departments (computer science and physics) into forming interdisciplinary quantum offerings, as opposed to launching new departments dedicated to quantum technology innovation.

University of Memphis

The University of Memphis engages in various research initiatives that potentially intersect with quantum computing, such as computational science, data science, and advanced materials research. The university's focus on innovation and technology positions it to contribute to the growing field of quantum information science.

The University of Memphis is already researching solutions to the same problems using classical computing methods in in its Intermodal Freight Transportation Institute (IFTI) through projects funded in partnership with the University of Memphis Division of Research and Innovation. Through its department of physics and material science, especially the work of Dr. Thang Hoang, The University of Memphis houses innovative research on nanoscale material discovery using optoelectronics and quantum dots. In the department of chemistry, Dr. Nathan DeYonker leads research on modeling the chemical structure of biomolecules. His group has experimented with new software that leverages

quantum mechanics to simulate proteins, thus reducing the overall computational burden of researching new biomolecules.

Select other academic institutions

Chattanooga State Community College (CSCC)

Chattanooga State Community College offers advanced degrees and certificate programs in computer science as well as a range of engineering fields including electrical, aerospace, and systems engineering. CSCC has been at the forefront of offering new degree programs for graduates seeking jobs in STEM fields such as cybersecurity and network infrastructure management, including a new aerospace engineering graduate certificate program in satellites, radars, and remote sensing - all programs with promising quantum-adjacencies.

"A company calls us up and says we are expanding to use quantum, and now we have a need for this or that skill for this type of employee - so let's get in the room with your faculty who teach these things, and let's go through the competencies that we need to build into the curriculum."
- CSCC Senior Leader

More recently, it initiated the process of forming a task force to identify opportunities to offer quantum-specific courses and non-degree-track training programs in quantum technologies. Its strategy has been to foster innovative partnerships with industry to offer interdisciplinary programs that prepare its students to secure high-demand jobs in emerging STEM fields like quantum.

Chattanooga State Community College is an invaluable partner for companies in Tennessee, like Volkswagen, who are looking to recruit skilled graduates into their labor force. For example, CSCC recently partnered with Volkswagen to offer Tennessee's first electrical vehicle engineering associates degree program: enrolled students gain firsthand experience working onsite with Volkswagen manufacturing equipment to supplement their curriculum at CSCC. Through its partnership with Volkswagen CSCC avoids the expense of purchasing its own heavy manufacturing equipment while offering significant added value for its students and the local economy. With an investment in a small number of new faculty members, CSCC was able to offer a new-in-kind, high-impact program through its strong partnership with Volkswagen – a potential model for

growth and innovation that other academic institutions in Tennessee may look to replicate.

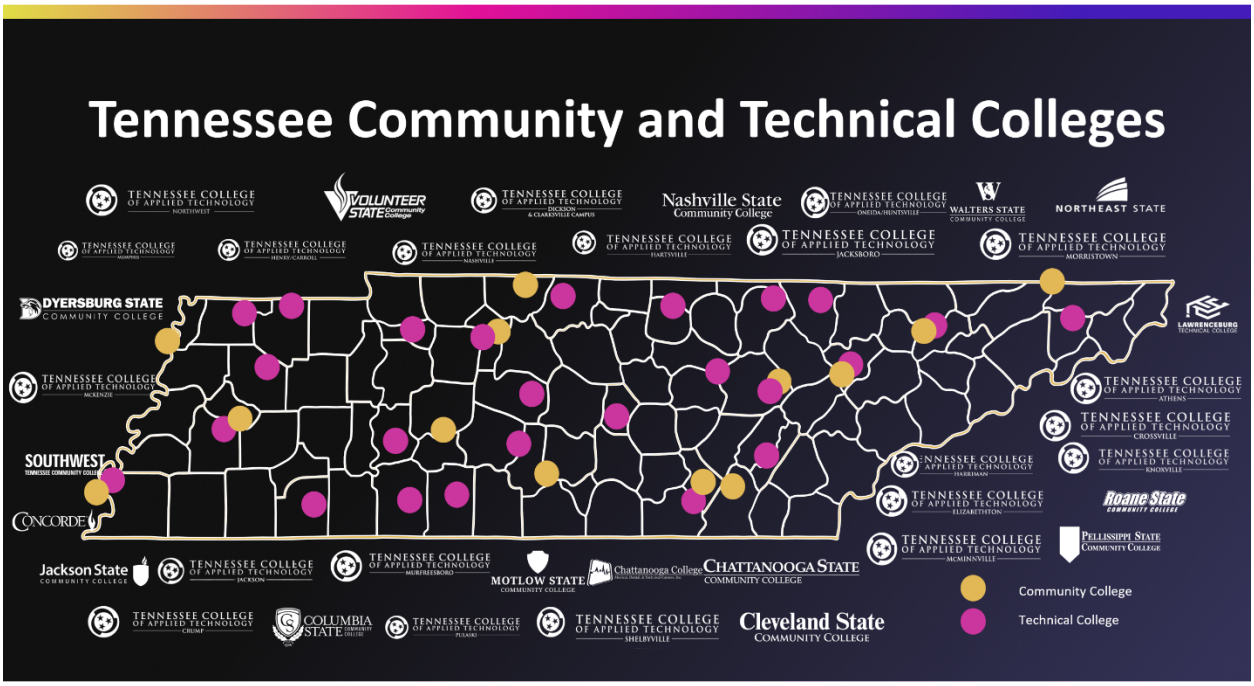
Pellissippi State Community College

Pellissippi State Community College is actively engaged in fostering quantum computing education and research, particularly through its Computer Information Technology program. The CIT program focuses on IT skills and prepares students for careers in four primary concentrations – cyber defense, networking, programming, and systems administration and management. The cyber defense concentration teaches students to monitor computer networks to prevent security breaches from intruders; networking graduates are equipped with the skills to maintain and implement networks of different sizes; programming concentrators choose between database, applications, and web programming; and systems administration and management graduates are prepared to install, configure, and upgrade networked operating systems.

Tennessee STEM Innovation Network (TSIN)

Although not affiliated with any one academic institution, the Tennessee STEM Innovation Network (TSIN) is a collaboration between the Tennessee Department of Education and Battelle, aims to enhance STEM education across the state. TSIN leads initiatives to improve STEM education quality for K-12 students in Tennessee, such as the Tennessee STEM School Designation and Regional STEM Innovation Hub programs, which promote participation in STEM statewide.

There are 8 Regional STEM Innovation Hubs in Tennessee located in Memphis, Chattanooga, Knoxville, Johnson City, Dyersburg, Cookeville, Murfreesboro, and Jackson. Each regional hub partners with its local school district to bring STEM professionals and teachers together to provide students with firsthand learning opportunities outside of the classroom. They also partner on professional development opportunities for teachers seeking to understand the new career pathways available to STEM graduates. With first-hand insight into the modern workforce, teachers can adapt their curriculums to teach the skills that will become most important for students.



Academic Programs, Centers, and Institutes

Tennessee universities offer a broad array of quantum-adjacent academic programs in their physics, electrical engineering, and computer science departments. Example programs from four of the state's largest universities – Vanderbilt, UTK, UTC and University of Memphis – are profiled in the diagram below in Figure 4. The examples in Figure 4, sourced directly from the university department websites[13], represent the existing academic programs in Tennessee that have the most promising latent potential for increased investment and curricular broadening into quantum technologies, given their direct relevance and applicability to the field.

[13] https://www.utc.edu/engineering-and-computer-science/graduate-programs/ms-engineering-programs
https://www.utc.edu/engineering-and-computer-science/academic-programs/computer-science-and-engineering
https://catalog.memphis.edu/content.php?catoid=31&navoid=1879
https://www.utk.edu/academics/programs#filters
https://www.vanderbilt.edu/vinse/
https://www.vanderbilt.edu/academics/program-finder/?school=School+of+Engineering

Additionally, Tennessee universities host myriad academic research centers and institutes that focus on quantum-adjacent subject areas, often offered in close partnership with federal, state, and/or private industry partners for a strictly defined purpose. These centers and institutes are often interdisciplinary in nature: they seek to translate and apply pure research from academic departments to real-world use-cases by drawing expertise across disciplinary silos to solve important problems. Given their well-defined objectives they are often founded with an explicit mission statement.

For instance, the University of Tennessee hosts centers like the Bredesen Center for Interdisciplinary Research and Graduate Education and the Joint Institute for Advanced Materials (JIAM). These centers focus on innovative research in materials science, photonics, and electronics, with applications ranging from quantum systems to advanced manufacturing.

Similarly, Vanderbilt University's Interdisciplinary Graduate Program in Materials Science and the Institute for Space and Defense Electronics (ISDE) contributes to advancing quantum technologies, exploring nanoscale phenomena, and developing algorithms for quantum computing and robotics, respectively. These academic centers serve as crucial hubs for interdisciplinary research and innovation, fostering collaboration between academia, industry, and government.

A total of 50 academic groups and institutes in Tennessee are profiled in further detail in the ecosystem study database,[14] and a selection of the areas of quantum technology they are working in are listed below.

- Aerospace & Defense
- AI (Artificial Intelligence)
- Cybersecurity
- Data Modeling & Simulation
- High-Performance Computing
- Material Science
- Nanotechnology
- Nuclear Energy Research
- Quantum Application Research
- Quantum Computing
- Quantum Physics
- Quantum Sensing
- Synthetic Biochemistry
- Telecommunications Infrastructure

Research Patents

As part of the analysis, a search for quantum-related patents originating in Tennessee over the last decade was conducted using The Quantum Insider Intelligence platform and other research tools. The results indicate fewer than 20 quantum-related patents in total, with the majority coming from the University of Tennessee, the University of Memphis, and Vanderbilt University. These patents cover areas such as quantum dots, nanostructures, cryogenic electronics, and sensors for nuclear radiation and photoluminescence. Additionally, the company Quantal Security (which ceased operations in July 2024) holds two patents for door and key management technologies that utilized quantum random number generation. It is important to note that this analysis was based on a keyword search which may not include all ancillary research that could support quantum technology so should be reviewed as indicative only.

[14] See "Academic Groups" tab, Quantum Ecosystem Study Excel

Research Centers

Industry Innovation Centers

Industry innovation centers, like the FedEx Institute of Technology and the Eastman Innovation Center, play important roles in Tennessee's technological landscape. These centers span industries such as automotive, chemicals, and advanced manufacturing, leveraging state-of-the-art facilities and expertise to drive innovation. For example, FedEx's center focuses on logistics technology research and development, while the Eastman center explores new and innovative chemical technologies.

Collaborative initiatives such as the University of Tennessee's Institute for Advanced Composites Manufacturing Innovation (IACMI) provide platforms for industry-academia partnerships, accelerating the adoption of quantum technologies in areas like materials science and manufacturing. The following innovation centers and hubs in Tennessee demonstrate the breadth and depth of interest in developing different sectors of Tennessee's economy and could become early collaboration partners in future quantum technology investment initiatives.

- Center for Advanced Vehicle and Extreme Environment Electronics
- Eastman Innovation Center
- FedEx Institute of Technology
- Institute for Advanced Composites Manufacturing Innovation (IACMI)
- Smart Grid Collaborative
- Tennessee Advanced Energy Business Council (TAEBC)
- Tennessee Center for Advanced Ceramic Technology (TCAT)
- Tennessee Innovation Crossroads
- Tennessee Manufacturing Extension Partnership
- Tennessee Solar Institute

Government Organization Centers

In Tennessee, government-affiliated research institutions play integral roles in advancing technologies for national security and strategic priorities. These centers, such as Oak Ridge National Laboratory (ORNL), possess advanced computational infrastructure and conduct research in areas such as materials science, sensing, and cryptography. Collaborative initiatives like the High-Performance Computing (HPC) capabilities at ORNL further bolster research capabilities and facilitate partnerships between academia, industry, and government agencies. Quantum technology has been explored

as one potential solution to latency issues impacting high-performance computers when simulating nuclear reactions at ORNL.

Given the size and scope of its R&D investment commitment from the federal government, and its mission to advance fundamental science for practical application, ORNL is the largest and perhaps the most important center of deep tech investment activity in Tennessee: it is where some of the most innovative breakthroughs take place in fields like material science and nuclear physics, where fundamental discoveries will determine the future commercial viability of quantum technologies. Tennessee's unique position as the home of ORNL gives a compelling investment profile for new technologies like quantum.

State-run agencies also exercise considerable influence in directing infrastructure investment strategy across the state. The Tennessee Valley Authority (TVA) and Electric Power Board (EPB) of Chattanooga are the two most important potential partners to consider for future quantum investment opportunities. Both are profiled in further detail below.

Oak Ridge National Labs (ORNL)

Oak Ridge National Laboratories (ORNL) is a federally funded research laboratory sponsored by the Department of Energy (DoE) and administered by the UT-Battelle LLC, a Tennessee-based contractor. ORNL plays a pivotal role in advancing scientific knowledge, technological innovation, and national security capabilities in the US through its multidisciplinary research programs. Founded in 1943 as part of the Manhattan Project, ORNL conducts research and development in various scientific and technological disciplines, focusing on energy, national security, materials science, nuclear science, and environmental management.

From its inception ORNL has emphasized nuclear fusion and fission research. To combat the sizeable costs in terms of time, electricity, and labor required to conduct experiments involving nuclear reactors, ORNL has also invested in advanced computational technology to simulate, model, and analyze nuclear reactions using supercomputers - a lower-cost alternative to "live" nuclear reactors. Simulations speed up the pace of research while reducing the cost of failure, and ORNL has routinely upgraded their high-performance computer (HPC) infrastructure on a ~5-year cycle (with the last occurring in 2022 with Frontier). Quantum technologies are under consideration as one potential solution to the latency issues undermining supercomputers when attempting to simulate complex nuclear reactions.

"Quantum could allow us to solve key problems in modeling nuclear reactions like neutron diffusion… I do not know if quantum is mature enough to enter those simulations [yet], but it is an energy-efficiency issue."
– Senior Scientist, ORNL

ORNL, one of the largest producers in the country of isotopes for medical purposes, has recently expanded its high-performance computing research capabilities to include biomedical research. It has focused on HPC simulations of protein interactions for medical and pharmaceutical purposes, including new drug discovery and cancer therapy. For purposes of simulating complex protein interactions, ORNL has considered quantum technology's future potential to improve efficiency in protein interaction modeling – currently an energy and computationally intensive exercise.

"We are trying to use new computational methods to design ligands (bonders) for these isotopes to get them to the cancer cells. So efficient modeling of drug-protein interactions is important, and that is one of the applications you hear about for quantum computing." – Senior Scientist, ORNL

ORNL's efforts to integrate quantum technology into its research have focused on incorporating quantum technology into their existing software stack and supercomputing hardware, rather than conducting stand-alone experiments with quantum devices. Given the comparatively advanced state of supercomputing technology relative to quantum, quantum's practical applicability in the near-term at ORNL is primarily limited to enhancing the classical software and supercomputing technology that ORNL is already using.

"All the setup on Frontier (HPC) is to integrate quantum with classical supercomputers… everyone envisions that these will be accelerators that are basically classical large-scale computers for the foreseeable future."– Senior Scientist, ORNL

Centers at Oak Ridge like the Spallation Neutron Source Center, High-Flux Isotope Reactor, and Nanophase Materials Sciences Center, among others, are likely to make the discoveries that will stimulate quantum ecosystem development.

Tennessee Valley Authority (TVA)

The Tennessee Valley Authority (TVA) is a federally owned corporation overseeing large-scale economic development in the Tennessee Valley, focused historically on hydroelectric electricity generation, river management, fertilizer development, and attracting new businesses to the region. With administrative headquarters in Knoxville and power-generation facilities in Chattanooga, the TVA's reach and influence across the state are broad, encompassing large-scale infrastructure management and environmental oversight in addition to community development. Although the TVA is owned by the federal government, it is not taxpayer funded and generates its own revenue.

To meet rising energy demand in the Tennessee Valley region, while simultaneously managing sustainability targets, TVA has diversified away from hydroelectric power generation in recent years to a range of sustainable energy sources including nuclear, battery-storage technology, solar, and wind power.

"We are trying to plan a system that is much more complicated than we have ever planned before. We have never had to worry about things on the distribution side like distributed generation, demand response, and all the different sensors that could be used." – Executive, Tennessee Power Supplier

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Sustainability efforts have sparked investment at TVA across a range of new sectors but have also presented a new set of challenges. One of the most pressing is the prohibitive up-front electricity requirements to operate new nuclear power facilities. Although Tennessee and TVA are actively seeking proposals for new nuclear power facilities, the responses they are receiving stipulate kilowatt requirements to operate the facility that make the investment uneconomical at current prices.

To combat rising electricity costs, TVA has experimented with new power distribution and transmission techniques to account for demand fluctuations, primarily using large data models in combination with supercomputers to predict future changes based on past demands. TVA has also allocated funds to UTC PhD students to experiment with

quantum sensors and quantum algorithm technology, and it has collaborated with its partners to put in place the infrastructure necessary to enable networked quantum communication in Tennessee.

However, TVA remains realistic about the long time-horizon and uncertainty accompanying quantum investment and is wary of quantum becoming another new entrant in a crowded field of promising technology. With Tennessee's investment focus areas tending to differ by region, with one part of the state investing in nuclear technology, another in electric vehicle technology, another in biomedical technology, and another in logistics technology, stakeholders across the state are distracted by their respective areas and may not want to take on the burden of quantum as "yet another initiative". Part of the challenge facing TVA is educating stakeholders about the possibility for quantum to be a connective tissue between existing technology investments, rather than a competitor (see SWOT analysis for further details).

Electric Power Board (EPB) of Chattanooga

The Electric Power Board (EPB) is an award-winning municipal utility in Chattanooga that provides electricity, internet, and telecommunications services. It manages the fiber optic network for Chattanooga (one of the world's fastest) and the surrounding areas, providing high-speed internet and video in addition to telephone services for businesses and individuals. EPB's highly automated power distribution grid includes sensors, meters, and communications infrastructure, including early-stage quantum sensing and networking infrastructure with real-time grid monitoring and self-healing capabilities.

EPB invests heavily both in traditional power distribution infrastructure – transformers, substations, optic cables – as well as grid modernization technologies, such as smart-switches, automatic metering (AMI) and drones, to optimize electricity distribution, cybersecurity software and network monitoring, renewable energy, and customer-facing technology solutions for seamless service delivery.

"EPB and our partnership positions Chattanooga to lead in the quantum space and serves as an example to other municipalities of supporting meaningful progress to advance quantum investments in their communities." – Executive Director, Quantum Economic Development Consortium

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Through its visionary leadership and partnerships with research universities in Tennessee, such as the University of Tennessee - Chattanooga, in addition to federal agencies such as the Department of Energy and NIST, the EPB is well positioned to support Tennessee winning future federal grant money for quantum energy-efficiency related projects. Given Tennessee's strong relationships with the ORNL, DOD, DOE, and the centralized control that EPB exercises over its power distribution capabilities, Chattanooga offers a logical geographical choice to conduct leading-edge quantum research, especially for critical infrastructure.

EPB recently expanded its core fiber optic network to 100 Gig capacity and is approximately halfway through a ~$70 million system upgrade. As part of this upgrade programme, they have also invested ~$4.5 million over three years to develop its quantum network, known as the EPB Quantum Network powered by Qubitekk, which is the first commercially available, professionally managed quantum network in the United States. This network has been designed for private companies, government, and university researchers to run quantum equipment and applications over a dedicated fiber environment.

"We started with the goal of trying to build quantum networks to interconnect these emerging quantum devices before anybody even knew what a quantum network was. We spent a decade doing that, and now we have the network in Chattanooga." – Executive, Quantum Security Company Partner

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EPB has partnered with Quibitekk to deliver the quantum network infrastructure. EPB's partnership with Qubitekk developed initially through overlapping projects and spin-offs at ORNL. Qubitekk expanded its partnership with ORNL to include EPB, and together they successfully developed and implemented a quantum network using EPB's innovative fiber optic technology.

The EPB Quantum Network is available to integrate with new quantum devices from partner organizations. EPB has partnered with, or is in discussions to partner with, several organizations including ORNL, DOE, UTC, and others. EPB's established, modular quantum network makes it a strong potential partner for new government agencies or private companies researching use-cases for quantum networking technology.

"EPB Quantum Network is a critical resource for lowering the barriers to entry for private companies, so we can move quantum technologies into real-world application." – Former U.S. Senator Bob Corker

The Electric Power Research Institute (EPRI)

The Electric and Power Research Institute (EPRI) is a US-based organization dedicated to working with government, industry, and academia to tackle difficult energy challenges and secure a sustainable energy future. With offices located in numerous major US cities and internationally, including a location in Knoxville, Tennessee,[15] EPRI hosts an R&D division dedicated to quantum technology research.[16] Through their "Quantum Challenges" initiative EPRI solicits potential solutions to pressing energy challenges using quantum-based technologies; EPRI also hosts community-based quantum events to introduce quantum industry and energy industry representatives. EPRI seeks to bridge the gap between early-stage, small-scale R&D companies working on quantum technology and large utility companies to facilitate the development of working quantum devices useable by the energy industry.

Quantum Companies

Companies in the Tennessee quantum ecosystem can be divided broadly into two categories:

1. **Quantum Supply Chain**: organizations engaged in the research, development, or commercialization of products that contribute to the broader ecosystem of quantum technologies, ranging from quantum software solutions, quantum control systems, and quantum hardware, to supply chain manufacturers such as photonics or cryogenic companies.
2. **Quantum Users:** organizations that want to leverage quantum technologies - for instance, a life science company exploring drug discovery through quantum computing and quantum hardware - to supply chain manufacturers such as photonics or cryogenic companies.

Although there are a limited number of companies in Tennessee that are building components directly for the quantum supply chain, there is by no means an absence of quantum-adjacent supply chain activity in Tennessee. While Alpha Rail and Qubit

[15] https://www.epri.com/about/locations
[16] *EPRI Home*. https://www.epri.com/quantum-computing.

Engineering are already commercializing early-stage quantum technology as a core part of their businesses, numerous other Tennessee-based companies, profiled in more detail in the following pages, are designing and manufacturing quantum-adjacent components for existing aerospace & defense, healthcare technology, automotive, and fiber-optic communications supply-chains.

Additionally, Tennessee is strategically situated amidst a hub of quantum-adjacent manufacturing companies whose proximity to Tennessee make them potential assets and partners in the state's emerging quantum supply chain. The potential for Tennessee to become a national hub for quantum technology becomes more apparent when considering the population of quantum companies actively working in and around Tennessee that have the potential to become leaders in the quantum ecosystem.

Quantum Supply Chain

Quantum Companies Based in Tennessee:

The quantum supply chain in Tennessee reflects the nascent state of the quantum supply chain nationally. However, there are already first-mover companies in Tennessee engineering explicitly for quantum application: AlphaRail and Qubit Engineering.

AlphaRail: AlphaRail, headquartered in Nashville, Tennessee, was founded in 2019 by Alex Luna (a graduate of the Creative Destruction Lab's Quantum Stream programme). The business aims to improve efficiency across the rail industry by providing innovative solutions that utilise the latest advancements in AI, quantum computing, and GPS technology. AlphaRail's platform utilizes advanced ML techniques to analyze and optimize rail operations by continuously evaluating network behavior patterns. This approach improves the accuracy and efficiency of rail networks to offer significant operational improvements and cost savings.

Qubit Engineering: Qubit Engineering, located in Knoxville, Tennessee, was founded in 2018 by a group of physicists and engineers (Dr. Barry Sanders, Dr. M. Zubairy) with expertise in quantum technology. They focus on developing new methods to distribute energy from wind turbines to areas with the highest demand, to realize efficiency gains for wind farms. Qubit Engineering leverages early-stage quantum technology to assist classical computers with the process of selecting sites for new wind turbines. Using their quantum-enabled technology to select locations to build new wind turbines in strategically distributed intervals throughout the state, Qubit Engineering has been able to lower the Levelized Cost of Energy (LCoE) for wind power. Qubit Engineering is also an active participant in the broader Tennessee ecosystem, supporting the ORNL

Innovation Crossroads initiative, partnering with Microsoft Azure Quantum, and collaborating with RES group to expand power generation capabilities in Tennessee.

Qubitekk: Qubitekk, a quantum hardware design and manufacturing company, partnered with EPB to launch and power the EPB Quantum Network to accelerate the process of bringing quantum technologies to market. The 100 Gig fiber-optic infrastructure at EPB will be available to commercial enterprises, as well as government and university researchers, to leverage for use with photonic qubits. Qubitekk prioritizes the manufacture and distribution of American-made technology to strengthen American leadership in quantum information science.

Quantum-Adjacent Companies Based in Tennessee:

Tennessee also boasts a range of companies whose manufacturing, design, and distribution profiles make them natural candidates for the quantum supply chain. These companies tend to specialize in the manufacturing and design of microelectronics components, fiber-optic infrastructure, and specialized industrial equipment, which are in turn sold primarily to the aerospace, defense, automotive, and telecommunications industries. A representative sample is provided below:

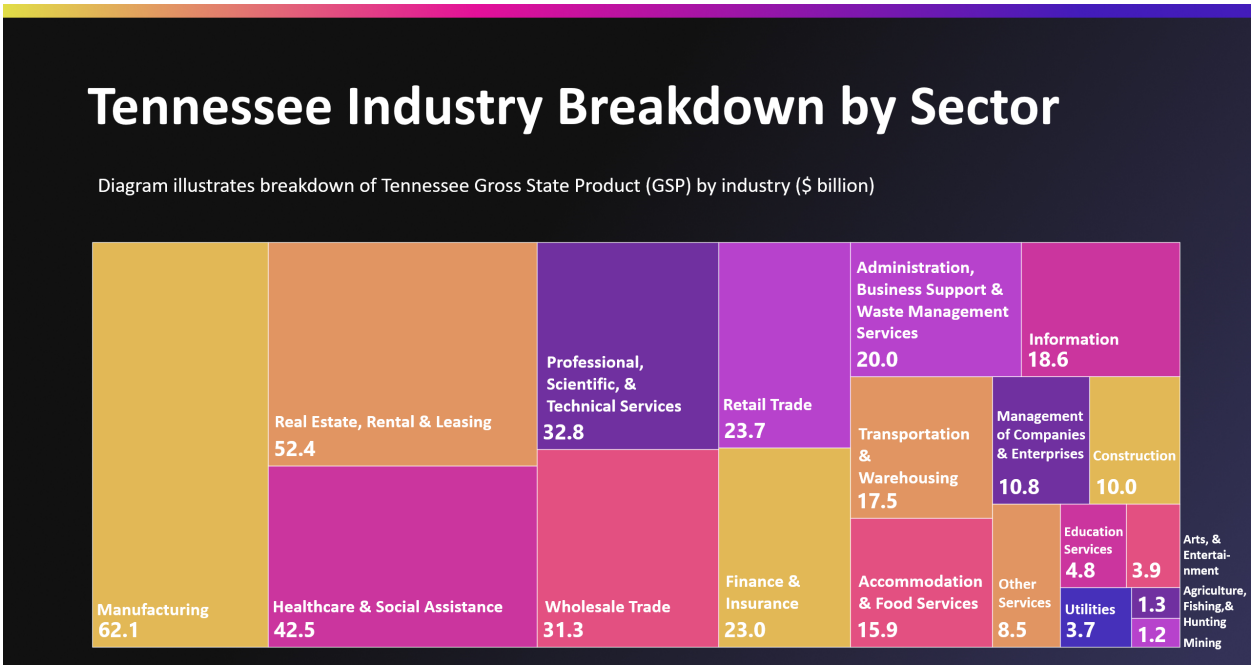
3SAE Technologies, Inc.: 3SAE has been based in Franklin, Tennessee for nearly 25 years and specializes in high-performance fiber optic tools and technologies. The company focuses on fiber optic preparation, fusion splicing, glass processing, and related applications, and holds multiple patents for innovative solutions. 3SAE serves global medical and defense industries with component and device manufacturing and provides critical support to universities and government research labs.

Sensorium Technologies: A spinoff of Vanderbilt University based in Nashville, TN, Sensorium Technologies aims to combine AI with advanced sensor systems, allowing businesses to innovate in fields like virtual reality (VR), augmented reality (AR), and human-computer interaction. The company also designs "metamaterials" for application in thin-film deposition and for gas detection in industrial and atmospheric monitoring.

Cryomagnetics, Inc.: Cryomagnetics, Inc. is an Oak Ridge National Lab spinoff that designs, manufactures, and services custom high-field magnet systems used in research, industrial, and medical applications. Cryomagnetics' products include superconducting magnets, cryostats, and various magnet-related components that are essential for MRI, particle accelerators, and fusion energy research.

Quantum Users

In 2024, Tennessee's gross state product was ~$447 billion.[17] The diagram below illustrates the proportional breakdown of Tennessee GSP across a selection of the state's largest industries. Transportation & Warehousing, given its centrality to Tennessee's economy, deserves focused attention as a development and investment opportunity in quantum technologies.



Based on interviews with local stakeholders in Tennessee, while there is a reasonable level of understanding of quantum technology's long-term potential, consistent feedback was that it was unclear how it could be used to drive business value in the short to medium term. This is consistent with feedback from companies internationally and rules out immediate profit-motivated engagement.

The Quantum Insider tracks over 400 corporates who have demonstrated an interest in quantum technology. These are typically large organizations with material research and development budgets. Internationally there is increasing engagement from larger corporates to research potential use cases for quantum technology. For example, Airbus

[17] *https://www.ibisworld.com/united-states/economic-profiles/tennessee/#:~:text=Overview%20of%20the%20Tennessee%20Economy&text=Tennessee's%20gross%20state%20product%20(GSP,past%20five%20years%20of%201.2%25.%20Shows%20as%20447.5bn%20in%202024.*

and BMW launched a quantum computing challenge[18] at the end of 2023 which covered potential use cases such as logistics optimization and quantum-enhanced autonomy. There is a clear trend of investment demand for new technological capabilities amongst Tennessee companies – especially in automotive, transportation, and logistics sectors. For example, Nissan hosted a Manufacturing Innovation Summit in Tennessee last year for purposes of identifying new product development opportunities. Their recent technology investments in Tennessee include IC.IDO, an automated process-validation software that reviews assembly line output for adherence to safety regulations. Similarly, FedEx's investments in autonomous trucking capabilities, refrigerated trucking optimization, and sensor-based logistics have all led to technological innovation at their Memphis Hub location in recent years. Their Memphis Hub is also heavily invested in robotics technology for package placement, and in cloud computing data transformation efforts, as it looks to reduce delivery times for consumers while reducing costs.

Investors

The investment landscape in Tennessee consists of a mixture of investor types, target sectors, and interests. With over 500 professionally registered investors based in the state across multiple investor classes, including venture capital firms, individuals/angels, private equity firms, family offices, accelerators, corporate venture arms, and government incubators. These investor types represent varying investment strategies and various interests across multiple sectors.

Most investors are sector agnostic, as opposed to seeking out targeted opportunities in technology, healthcare, energy, education, materials, and chemicals.

> *"I do not think that we think about quantum that much. We are open to investing in any space. We are industry agnostic investors – we are open to exceptional founders and backing their ideas." – Founder, TN Early-Stage Investment Firm*

Of these, a subset has a history of investing in deep tech. 30 Tennessee-based firms were identified as having the highest likelihood of having an interest in quantum technology, given their history of investing in deep tech or a mandate that considers

[18] *Airbus and BMW Quantum Computing Challenge 2024 | Airbus*. 7 Dec. 2023, https://www.airbus.com/en/innovation/digital-transformation/quantum-technologies/airbus-and-bmw-quantum-computing-challenge

deep tech. Deep tech includes blockchain, artificial intelligence, biotech, robotics, advanced materials, life sciences, and quantum technology, among others. Speaking to individuals from these firms in detail was beyond the scope of this report.

A non-exhaustive list of VC Firms targeting deep tech opportunities in Tennessee includes:

- **Nashville Capital Network (NCN):** A network of angel investors and venture capitalists providing funding and support to early-stage companies across various sectors, including healthcare and technology. NCN's investor partners are founders and executives of successful healthcare and technology companies throughout the southeastern US. NCN leverages these individuals to identify, evaluate, and accelerate the success of high-growth early-stage companies. It specializes in $2-$10 million investments in companies that have already formed and raised seed capital. Historically NCN's most prominent investments have been in health services and health tech companies such as Ovation Healthcare, Modify Health, and CareHarmony, recent investments have tended to favor companies specializing in deep tech, such as Unity AI and spiny.ai, as well as companies that intersect health and deep tech, such as Concert Genetics. A company like Concert Genetics may already be taking preliminary steps to begin using quantum-enabled algorithms for new drug discovery and genetic imaging research.

- **Innova Memphis:** Innova Memphis invests in early-stage biosciences, technology, and especially AgTech companies. Innova seeks to close the funding gap facing early-stage entrepreneurs as other firms have shifted their focus to profitable companies. Through its investment in Tennessee AgTech companies, Innova has a direct interest in the advancement of quantum technologies, which have the potential to materially increase the value of their portfolio companies such as Solitech Wireless, a company that makes sensors for multifunctional usage on farmsteads including soil moisture levels, temperature, and humidity and CO2 levels. The sensors enable farmers to make real-time decisions throughout the growing season in a user-friendly interface, and to track crop throughput. The proprietary software, called Signal, would be directly impacted if quantum sensing technology – a rapidly developing field that will produce sensors far more capable than their classic counterparts – advances to the point of commercial viability. As quantum sensing innovation accelerates and continues to receive extensive funding for defense purposes, it is inevitable that breakthroughs in fundamental

research will spill over into commercial markets in which Innova Memphis is already an active participant.

- **Jumpstart Foundry:** Jumpstart Foundry is a healthcare-focused VC and accelerator that supports innovative health and wellness companies. JSF is owned by Angel Capital Group, a network of angel investors. Jumpstart is based in Nashville and offers accelerator programming for healthcare companies in the region. It also offers investment fund opportunities, connecting regional investors and companies. Jumpstart has recently begun to explore acceleration efforts in other fields as well, including robotics and artificial intelligence.

- **InvestTN:** A collaborative initiative between LaunchTN and the Tennessee Department of Economic and Community Development (TNECD), InvestTN makes equity investments into Tennessee-located start-ups (Pre-Seed, Seed, Series A and B) and venture capital funds. Through LaunchTN's unique statewide network of entrepreneur centers and industry focused partners, start-ups receive access to mentors, technology transfer, investors and professional service advisors.

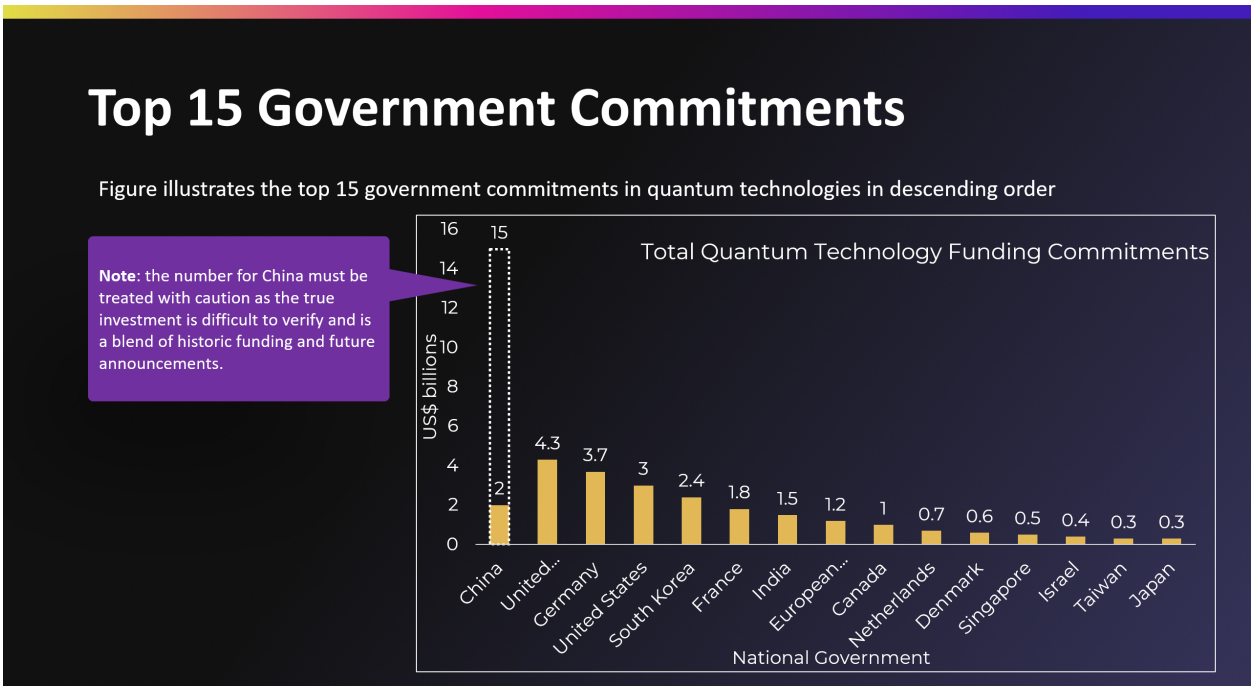
There are no specialist quantum technology investment organizations in the Tennessee region which is not unique; globally there are 5-10 investment organizations with a specialization in the quantum technology market.

National and International Context

This section explores the adoption of quantum technologies, analyzing the motivations driving this trend from first an international perspective and then examining developments made by the United States in its pursuit of technological leadership, competitive advantage, and the development of a vibrant quantum ecosystem to power its growing quantum economy. This includes a high-level overview of the National Quantum Initiative (NQI) Act, the CHIPS and Science Act and measures for national security, including fiscal commitments for specific quantum technologies and focused application areas outlined in the National Defense Authorization Act.

International Context

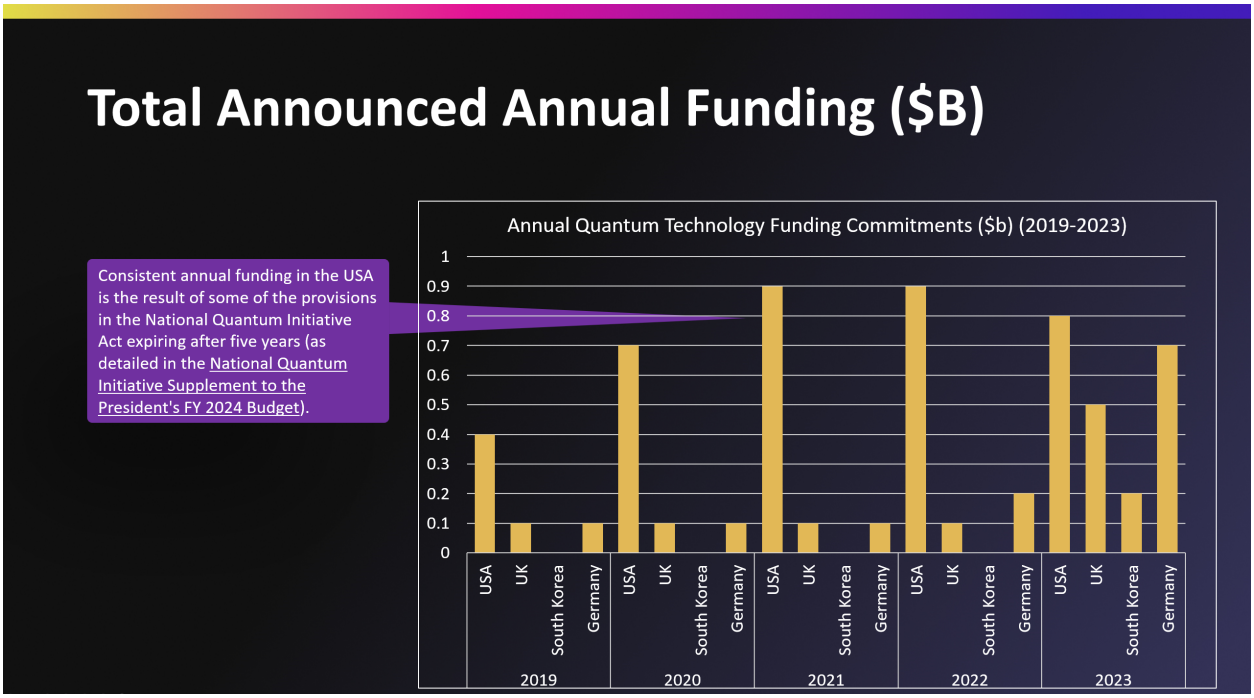
The disruptive potential of quantum technologies across communications, computing, sensing, timing, and security has fueled public and private investments globally. According to The Quantum Insider Intelligence platform, 25 nations have committed a combined US $40 to 50 billion in total funding for the development of quantum technologies, enabling infrastructure, skills and workforce, and economy, with around half having published national quantum strategies, initiatives, or roadmaps. Governments often make ambitious funding commitments that must go through political approval processes before funds can be allocated. These funds are typically distributed through trusted institutions, supporting a combination of scientific research and commercialization initiatives. The figure below shows the top 15 nations based on total commitments to investing in quantum technologies.



The top 5 nations by government commitments are: China leading with $15 billion, followed by the UK with ~$4.3 billion, Germany with ~$3.7 billion, the United States with ~$3 billion and South Korea with ~$2.4 billion. Note: the number for China must be treated with caution as the true investment is difficult to verify and is a blend of historic funding and future announcements.

The consistent annual funding in the USA from 2019-2023 originated from provisions in the National Quantum Initiative Act that guaranteeing a set amount of recurring annual funding for quantum technology, set to expire after 2023.[19] The elevated levels of funding committed by the United States demonstrates quantum technology's sustained importance as a priority area of national infrastructure and security investment. If classified DoD programs are accounted for, the net amount of US quantum investment would likely be greater than the published amount.

[19] Subcommittee on Quantum Information Science and Committee on Science. *National Quantum Initiative Supplement to the President's FY 2024 Budget*. National Science and Technology Council, Dec. 2023.



Behind these numbers is a highly nuanced picture where nations leverage their strengths in quantum research and / or address capability gaps through policy and targeted investments to foster quantum ecosystem development. Crucially these are being implemented through a phased approach and for the longer term, recognizing that it takes time to build an ecosystem.

Three quantum ecosystem case studies are examined for China, the UK, and South Africa. While each nation has committed to a government-led quantum technologies program, including research, workforce development, commercialization, and engagement with industry and policy makers, there are stark contrasts in setting priorities, funding commitments (billions for China and the UK, millions for South Africa), the scale of ambition and deployment, and making the most of the available resources to maximize innovation and impact.

For instance, the UK and China are developing quantum computers with different qubit modalities, while South Africa does not have the resources to do so and is instead building partnerships to enable access to develop algorithms and applications. China is developing quantum communication networks spanning several thousand kilometers (fiber and satellites), the UK is more modest at several hundred kilometers (fiber), and South Africa's quantum network (fiber) is at tens of kilometers.

Valuable lessons can be learned from how each nation has mobilized its people, capabilities, and assets to create a tailored quantum strategy to support the development of a new industry and benefit wider society.

China

China has enshrined quantum technologies in its 14th Five Year Plan (2021),[20] an economic blueprint to consolidate resources, establish national laboratories and focus on developing quantum communication technologies (intra-city, inter-city, and free-space), quantum computing prototypes (superconducting and photonics qubits), a practical quantum simulator and making breakthroughs in quantum precision measurement technology.

In 2021, China demonstrated an integrated quantum communication network[21] for secure Quantum Key Distribution (QKD). The network spans 4,600 kilometers linking the cities of Beijing, Jinan, Shanghai, and Hefei, and combines over 700 optical fibers on the ground (supported by 32 "trusted relay nodes") and two ground-to-satellite quantum communication links.

The University of Science and Technology of China (USTC) is a key driver for R&D in quantum technology. Researchers at USTC plan to expand their network by collaborating with partners in Austria, Italy, Russia, and Canada. They are also focused on developing lower-cost satellite QKD technologies, including 'cube-sats'.

This technological feat is underpinned by a unified strategy and (undisclosed) funding that encompasses focused scientific research, engineering, multi-disciplinary and multi-entity collaboration, and close coordination between national and regional bodies.

UK

The UK was one of the first to announce a comprehensive National Quantum Technologies Program (NQTP)[22] in 2013/4 to accelerate quantum research from laboratory to market and create a new industrial sector. Four, university-led quantum technology hubs were created in imaging, sensing and timing, communications and computing. Since then, the NQTP has expanded to include 5 Centers for Doctoral

[20] Center for Security and Emerging Technology. *People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035*.
[21] Johnston, Hamish. "Quantum Cryptography Network Spans 4600 Km in China." *Physics World*, 7 Jan. 2021, https://physicsworld.com/a/quantum-cryptography-network-spans-4600-km-in-china/.
[22] *UK National Quantum Technologies Program*. https://uknqt.ukri.org/.

Training[23] in quantum technologies, entrepreneurial support for researchers (such as the Quantum Technology Innovation Centre[24] incubator), establishing a dedicated National Quantum Computing Center (NQCC),[25] precision measurements for testing quantum devices at the National Physical Laboratory's Quantum Metrology Institute,[26] and setting ambitious technological goals through the National Quantum Strategy Missions,[27] One mission is to deploy the world's most advanced quantum network at scale by 2035.

The UK has developed its own quantum network[28] through a collaboration between the UK Quantum Communications Hub, Toshiba and ID Quantique, to establish multi-node metropolitan networks in Bristol and Cambridge linked by 410 km of fiber through the National Dark Fibre Facility (NDFF).

Satellite QKD is also an active area of research innovation. A recent collaboration[29] between UK and German researchers proposed using two quantum memories with different lifetimes as quantum repeater nodes to overcome barriers in the development of a global quantum communications network.

Commercialization of quantum technologies through industry-led innovation is managed by Innovate UK via its Quantum Challenge program.[30] As of May 2024, this initiative has allocated GBP £227 million to 207 projects, involving 157 businesses and 44 research organizations. These businesses have subsequently raised over GBP £610 million in private investment according to TechUK.[31]

Building on its early-mover advantage and progress in advancing a new quantum sector, including the creation of 49 startups, the UK government announced[32] a GBP £2.5 billion

[23] *Centers for Doctoral Training*.https://www.ukri.org/what-we-do/developing-people-and-skills/epsrc/studentships/centres-for-doctoral-training/.
[24] "Home." *QTIC*, https://qtic.co.uk/.
[25] "National Quantum Computing Centre." *NQCC*, https://www.nqcc.ac.uk/.
[26] "Quantum." *NPLWebsite*, 9 July 2021, https://www.npl.co.uk/quantum.
[27] "National Quantum Strategy Missions." *GOV.UK*, https://www.gov.uk/government/publications/national-quantum-strategy/national-quantum-strategy-missions.
[28] *UK Quantum Networks*. https://uknqt.ukri.org/success-stories/uk-quantum-networks/.
[29] *Optica Publishing Group*. https://opg.optica.org/opticaq/viewmedia.cfm?uri=opticaq-2-3-140&html=true.
[30] *Commercializing Quantum Technologies Challenge*. https://www.ukri.org/what-we-do/browse-our-areas-of-investment-and-support/commercialising-quantum-technologies-challenge/.
[31] *Quantum Commercialization: A Review of the UK Funding Landscape*. https://www.techuk.org/resource/quantum-commercialisation-a-review-of-the-uk-funding-landscape.html.
[32] "National Quantum Strategy (Accessible Webpage)." *GOV.UK*, https://www.gov.uk/government/publications/national-quantum-strategy/national-quantum-strategy-accessible-webpage.

strategy in 2023. This strategy aims to link investment to impact, with the goal of delivering a quantum-enabled economy by 2033.

South Africa

Launched in 2021, the South African Quantum Technology Initiative (SA QuTI) seeks to create a globally competitive research environment and grow a local quantum technology industry in South Africa. The funding commitment to date is US $34 million according to The Quantum Insider, which ranks it 32 out of the 39 countries surveyed.

Recognizing it cannot compete with the billions invested by other nations, South Africa's strategy brings together research, academia, government, and industry to drive innovation and commercial adoption across 3 quantum technology pillars:

- **Quantum computing**: building applications through partnerships with existing providers like IBM Quantum.
- **Quantum communications**: holistic technology development bringing together disparate research activities (sources, detectors, protocols and networks), to establish local quantum secure links between universities, government, and industry.
- **Quantum sensing**: accelerate the development of products for medicine, aerospace, military and telecommunications sectors.

The SA QuTI also emphasises ecosystem development through education and training, capacity building at existing centers, establishing new quantum centers, developing flagship projects to bring the community together, and facilitate commercialization through technology transfer.

While less mature than other quantum technology programs, the drive and commitment of stakeholders to invest in researchers and "side-step the competition" should not be underestimated.

Partnerships

Governments around the world are fostering international collaboration in quantum research, leveraging existing science, diplomatic and security alliances. Given that quantum technology is still nascent, most international cooperation focuses on R&D exchanges and providing access to training, infrastructure and software tools and platforms. Commercial players also drive cross-border collaborations to engage early adopters. According to The Quantum Insider Intelligence Platform, there are over one thousand tracked partnerships globally pursuing a range of objectives, including driving

innovation, creating use-inspired applications, and skills and workforce development across government, academia, and the private sector.

Quantum Workforce

Developing a quantum-skilled workforce is a key priority for most nations. There are 195 universities around the world offering quantum technology programs and 55 master's degrees have been created.[33] The EU, UK and India have the highest number of graduates in quantum technology related fields.

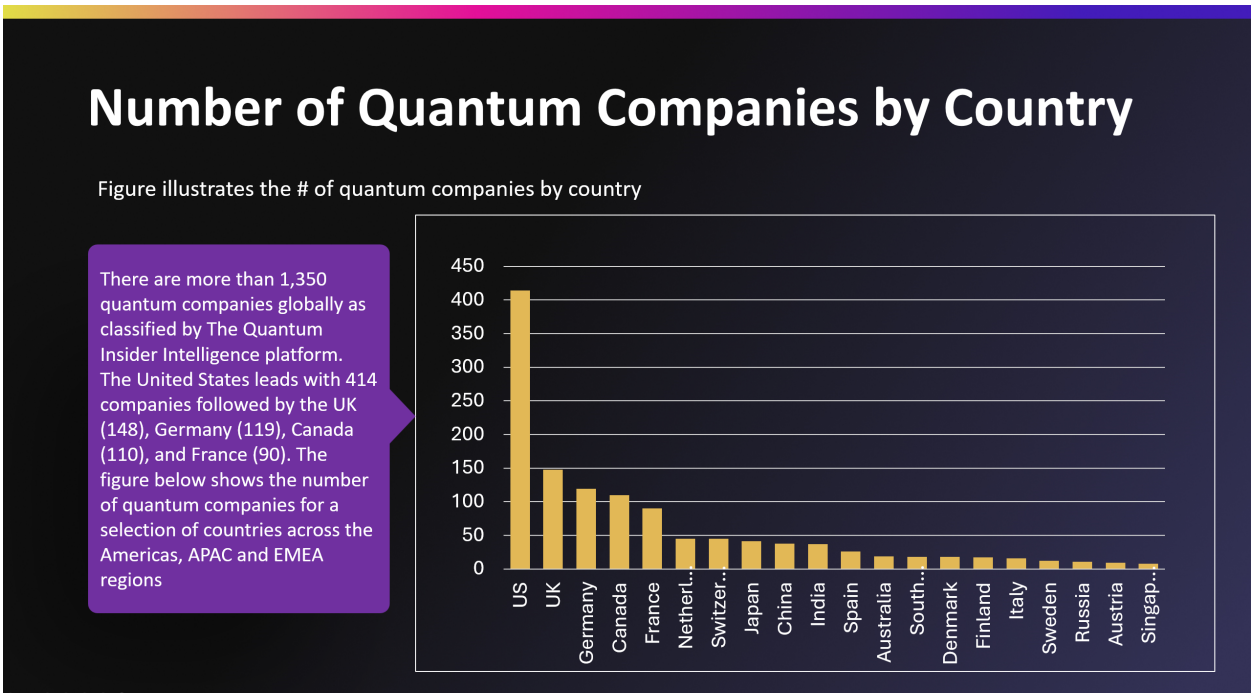
Through its national quantum strategy[34], France is looking to enrich its quantum workforce by training 5,000 people from technicians to PhDs. This demonstrates the growing maturity of the quantum sector, the increasing demand for quantum technology skills and the emergence of new roles required to serve the quantum industry.

Quantum companies

There are more than 1,350 quantum companies globally as classified by The Quantum Insider Intelligence platform. The United States leads with 414 companies followed by the UK (148), Germany (119), Canada (110), and France (90). The figure below shows the number of quantum companies for a selection of countries across the Americas, APAC and EMEA regions.

[33] *Steady Progress in Approaching Quantum Advantage | McKinsey*. https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/steady-progress-in-approaching-the-quantum-advantage..

[34] "France 2030 : Point d'étapes trois ans après le lancement de la stratégie nationale des technologies quantiques et lancement du programme Proqcima." *enseignementsup-recherche.gouv.fr*.



The international picture for quantum technology is vibrant, collaborative, with stark inequalities in funding and resources, with nations striving for technological pre-eminence and / or global competitiveness, carving out their respective niches.

The United States is a clear leader on the global stage, collaborating with trusted partner nations while pursuing its own quantum strategy to accelerate its technological leadership and rising competition from China. The next section examines the United States quantum strategy from both public and private perspectives to foster a connected ecosystem.

Quantum Technology in the USA – National Context

Overview

The U.S. government's motivations for investing in quantum technologies are enshrined in the 10-year National Quantum Initiative Act, passed by Congress in 2018. The NQIA adopts a comprehensive approach to advance the United States' technological leadership in quantum science and technology and provide a coordinated federal program to accelerate quantum research and development for the economic and national security of the nation. The NQIA authorizes the National Institute of Standards and Technology (NIST), National Science Foundation (NSF), and the Department of Energy (DOE) to strengthen and expand QIS programs, centers, and consortia, and calls

for the coordination of QIS R&D efforts across the U.S. Government, including the civilian, defense, and intelligence sectors.

The NQIA is supported by the following bodies:

- The Subcommittee on Quantum Information Science (SCQIS) coordinates Federal R&D in QIS under the National Science and Technology Council (NSTC) Committee on Science, co-chaired by OSTP, NIST, NSF, and DOE. SCQIS aims to strengthen U.S. leadership in QIS over the next decade.
- The Subcommittee on Economic and Security Implications of Quantum Science (ESIX), co-chaired by OSTP, DOD, DOE, and NSA, addresses the economic and security aspects of QIS.
- The National Quantum Initiative Advisory Committee (NQIAC) advises the President, SCQIS, and ESIX, providing independent assessments and recommendations for the NQI Program.
- The National Quantum Coordination Office (NQCO) within OSTP supports daily activities, interagency coordination, and public outreach, with staff from various Federal agencies.

The NQIA prioritizes a science-first strategy, focusing on fundamental research to build a durable foundation for future innovations. The Act emphasizes the creation of a quantum-smart workforce through education and training programs, fostering collaboration between academia, government, and the private sector to accelerate development and commercialization.

The initiative supports the provision of critical infrastructure necessary for quantum research and development nationwide, and formally adds NASA as a quantum research agency. While prioritizing national interests, the Act also promotes strategic international cooperation to advance global quantum science and technology efforts.

Since its enactment, annual funding for the NQIA has steadily increased, doubling from $449 million in FY 2019 to a requested $968 million for FY 2024. In a report published in June 2023,[35] the NQIAC made a series of recommendations including the renewal and expansion of the NQIA beyond its ten-year remit to ensure the United States maintains its leadership in Quantum Information Science (QIS).

[35] National Quantum Initiative Advisory Committee. *Renewing the National Quantum Initiative: Recommendations for Sustaining American Leadership in Quantum Information Science*. June 2023.

In November 2023, the House Committee on Science, Space, and Technology passed the National Quantum Initiative Reauthorization Act (H.R. 6213). Currently, the bill holds the status of "Introduced" and must still be approved by both the House and the Senate before being signed into law by the president.

Getting the science right

The national quantum strategy was developed with the aim to understand the applications and timelines required to realize the benefits of QIS in society and the barriers preventing it from doing so. This necessitated a focused approach to QIS research and the creation of dedicated QIS centers.

The NQIA has established 10 new quantum research centers and institutes at NIST, NSF, and NASA and strengthens support for DOE centers. The NSF launched 5 Quantum Leap Challenge Institutes each awarded ~$25 million, and DOE committed to fund 5 National QIS Research Centers, fostering multidisciplinary teams. These centers, linked to academia, labs, and industry, tackle key QIS challenges, drive technology, and training, and complement existing programs, including the Department of Defense (DOD) research center expansions under the National Defense Authorization Act (NDAA), bringing the total number of national centers to 14. These are listed below.

NSF Quantum Leap Challenge Institutes (5)

Name	Location	Description
Q-SEnSE: Quantum Systems through Entangled Science and Engineering	University of Colorado, CO	Developing quantum sensors and networks for fundamental science and practical applications.
HQAN: Hybrid Quantum Architectures and Networks	University of Illinois Urbana-Champaign, IL	Hybrid quantum systems and networks to advance quantum computing and communication.
CIQC: Challenge Institute for Quantum Computation	University of California, CA	Overcoming key challenges in quantum computation through interdisciplinary research.
QuBBE: Quantum Sensing for Biophysics and Bioengineering	University of Chicago, IL	Quantum sensing technologies for applications in biophysics and bioengineering.
RQS: Institute for Robust Quantum Simulation	University of Maryland, MD	Creating robust quantum simulations to solve complex scientific problems.

DOE QIS Research Centers (5)

Name	Location	Description
Q-NEXT: Next Generation Quantum Science and Engineering	Argonne National Laboratory, Lemont, IL	Develop the science and technology to control and distribute quantum information.
C2QA: Co-design Center for Quantum Advantage	Brookhaven National Laboratory, Upton, NY	Co-designing quantum hardware and software to achieve quantum advantage.
SQMS: Superconducting Quantum Materials and Systems Center	Fermi National Accelerator Laboratory, IL	Develops superconducting quantum materials and systems for quantum computing.
QSA: Quantum Systems Accelerator	Lawrence Berkeley National Laboratory, CA	Accelerate the development of quantum systems for practical applications.
QSC: The Quantum Science Center	Oak Ridge National Laboratory, TN	Advancing quantum materials, algorithms, and sensors.

NDAA QIS Research Centers (4)

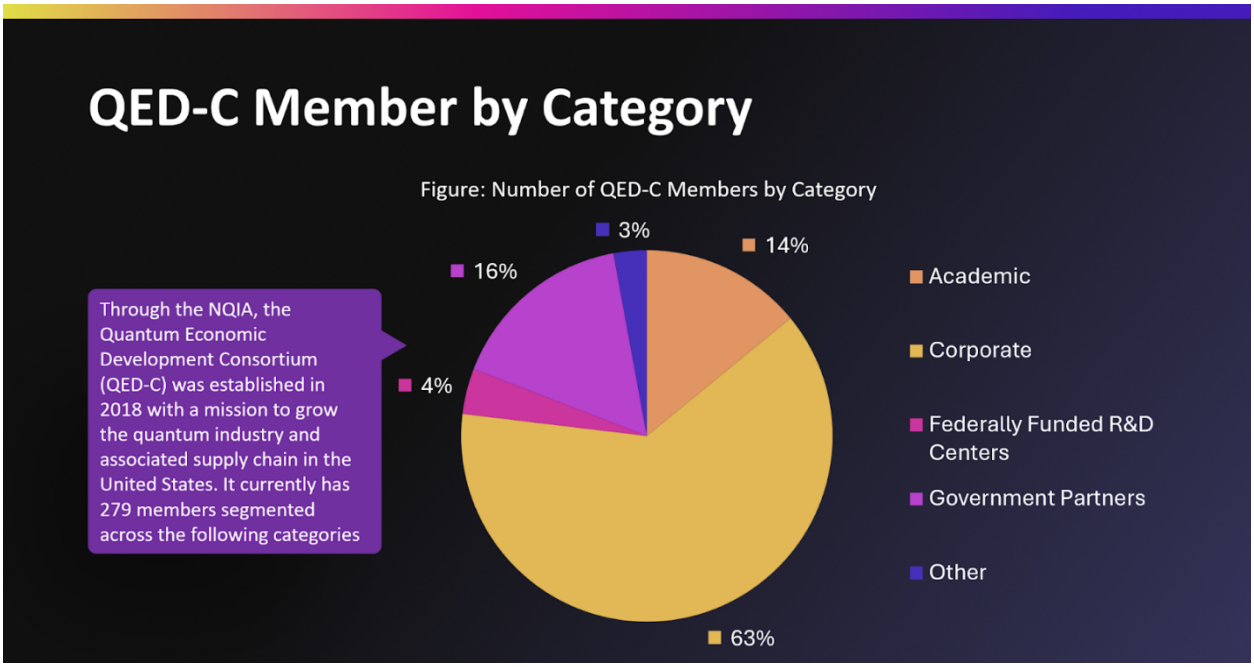
Name	Location	Description
LQC: LPS Qubit Collaboratory	Laboratory for Physical Sciences, MD	Develops qubit technologies for quantum computing and communication.
AFRL: Air Force Research Laboratory	Wright-Patterson Air Force Base, OH	Conducts research in quantum information science for defense applications.
NRL: Naval Research Laboratory	Washington, D.C.	Quantum technologies for naval and defense applications.
ARL: Army Research Laboratory	Adelphi, MD	Develops quantum technologies for Army and defense applications.

Enabling people

To date, the United States has signed 13 international cooperation joint agreements for Quantum Information Science (QIS) with Australia, Canada, Denmark, Finland, France, Germany, India, Japan, the Netherlands, the Republic of Korea, Sweden, Switzerland, and the United Kingdom. A key component of these agreements is the development of the next generation of scientists and engineers. Recognizing the global nature of quantum talent and the immense value of collaboration and shared experiences, the Entanglement Exchange[36] online portal has been established. This platform facilitates "people exchanges" for students, researchers, and professionals among the signatory nations.

Growing the quantum industry

Through the NQIA, the Quantum Economic Development Consortium (QED-C)[37] was established in 2018 with a mission to grow the quantum industry and associated supply chain in the United States. It currently has 279 members segmented as shown below.



[36] "*Entanglement Exchange*." https://entanglementexchange.org/.
[37] "Home." *QTIC*, https://qtic.co.uk/.

While beginning from a national context, the QED-C is expanding internationally. It is a member of the International Council of Quantum Industry Associations[38] along with Quantum Industry Canada (QIC), the Quantum Strategic Industry Alliance for Revolution (Q-STAR), and the European Quantum Industry Consortium (QuIC), to strengthen communication and collaboration among its member consortia; and has announced[39] it is welcoming applications from corporations and research institutes in India.

While the United States is broadening its international relationships with trusted QIS partners, it is also strengthening its domestic capabilities and defences, expressed through the CHIPS and Sciences Act and the National Defense and Authorization Act (NDAA) described next.

CHIPS and Science Act 2022

The CHIPS and Science Act allocates $280 billion to strengthen U.S. semiconductor manufacturing, R&D, and workforce development, and includes substantial funding for QIS and other advanced technologies. Its goal is to strengthen U.S. technological competitiveness and national security by reducing reliance on foreign semiconductor suppliers and promoting innovation. This section examines the quantum-related aspects of the act, noting it is not just about semiconductor chips, but about science and talent as well.

The act authorizes $153 million annually for quantum-specific programs from 2023 to 2027, divided as follows:

- $100 million for the Quantum Science Network (DOE),
- $30 million for the Quantum User Expansion for Science and Technology Program (DOE),
- $15 million for Quantum Networking and Communications Research and Standardization (NIST),
- $8 million for the Next Generation Quantum Leaders Pilot Program (NSF).

Accelerating innovation in quantum network infrastructure is emphasized and the act authorizes a research, development, and demonstration program to support this goal, and standards development through NIST.

[38] Tomasetti, Amanda. "Quantum Consortia QIC, QED-C, Q-STAR and QuIC Form International Council to Enable and Grow the Global Quantum Industry." *QED-C*, 31 Jan. 2023, https://quantumconsortium.org/quantum-consortia-qic-qed-c-q-star-and-quic-form-international-council-to-enable-and-grow-the-global-quantum-industry/.
[39] *ibid*

To grow a diverse, domestic quantum workforce, the act includes several initiatives: expanding the Federal Cyber Scholarship-For-Service program to include quantum computing, adding quantum components to the DOE Computational Science Graduate Fellowship program, and creating the NSF Next Generation Quantum Leaders Pilot program. Additionally, it authorizes QIS education and workforce development programs, including a quantum education pilot program. The Quantum User Expansion for Science and Technology (QUEST) program ensures researchers have access to leading-edge quantum computing resources.

Quantum information science and technology is identified as a key focus area, highlighting its importance for U.S. competitiveness and national security. However, one key aspect missing from the act is bridging the gap between science R&D and commercial applications.

National Defense and Authorization Act (NDAA)

The National Defense Authorization Act is a key federal statute that outlines the annual budget, expenditures, and policies for the DOD. It allocates funding for defense-related activities, including personnel, procurement, research and development, and other national security operations. The NDAA also addresses defense issues such as military justice, service member benefits, and initiatives to advance technological capabilities and national security infrastructure. The total funding for the 63rd annual NDAA is ~$886 billion for FY 2024. This section highlights the quantum-related aspects of the NDAA.

The act authorizes the DOD to support and coordinate QIS research and development to advance the technology readiness level of quantum technologies in the U.S. and to develop a skilled quantum workforce. This includes establishing QIS research centers within each military branch.

Additionally, the NDAA includes a pilot program to test, evaluate, and apply quantum and quantum-hybrid technologies to address defense, military, and national security challenges, particularly focusing on near-term applications like annealing quantum computing.

To foster public-private partnerships and workforce development, the NDAA promotes the expansion of talent exchange programs with private sector entities working on quantum technology. It also authorizes a fellowship program for students engaged in QIS research.

In terms of quantum networking and communication, the NDAA funds initiatives such as a distributed quantum networking testbed and the development of a next-generation ion trap quantum computer at the Air Force Research Laboratory.

Finally, the NDAA mandates the creation of ethical guidelines for the use of QIS technology and initiatives to mitigate cybersecurity threats posed by these advanced technologies.

Other

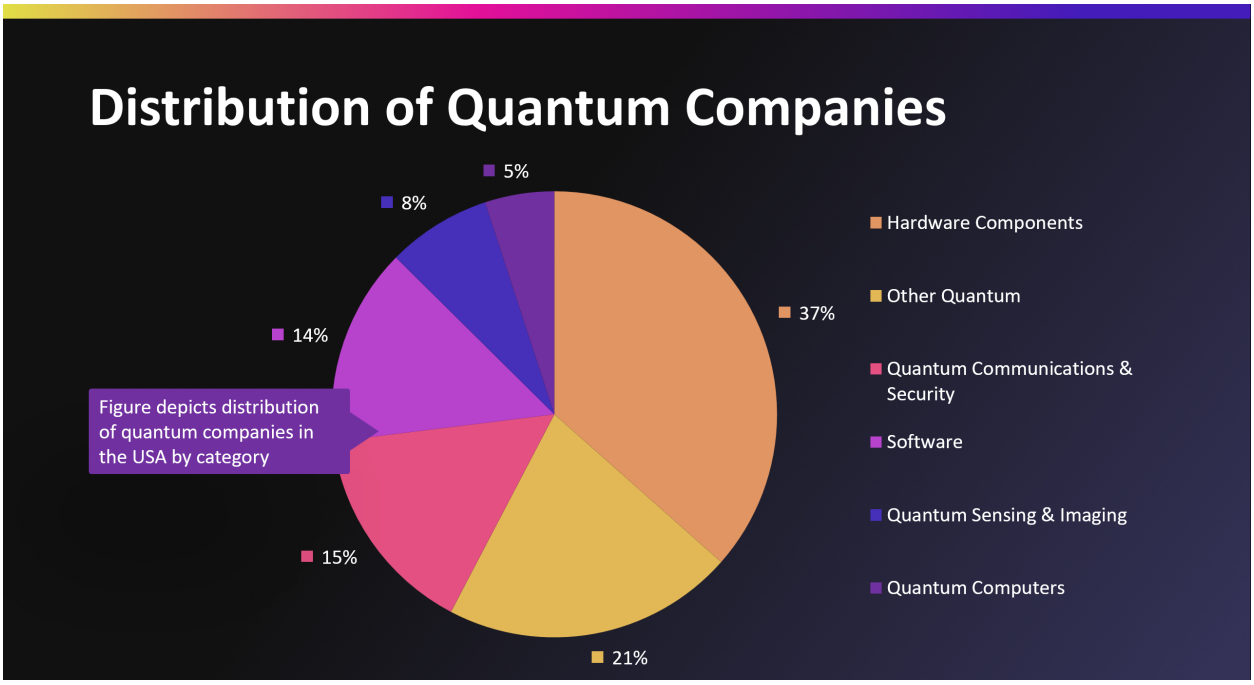
The United States has recognized the intensifying international competition in quantum technology and is moving beyond a science focus of the last 5 years to commercialization, deployment and impact. This shift is evident in recent funding and policy changes aimed at ecosystem development. The NSF Regional Innovation Engines ("NSF Engines") initiative, with a $160 million investment over 10 years, is one example, fostering new business creation and economic expansion in critical technological sectors. Additionally, Economic Development Administration (EDA) grants, like the $41 million awarded to Colorado's Elevate Quantum, underscore a regional approach to build quantum infrastructure, create significant jobs, and unlock economic impact through a combination of federal, state, and private investments.

Looking ahead, the United States is reinforcing its strategic focus in quantum technology through various initiatives. The Department of Defense's Office for Strategic Capital (OSC), established in December 2022, aims to attract and scale private capital investment in critical technologies, including quantum. NASA's role is anticipated to expand under the reauthorization of the NQIA to advance space-based quantum technologies through the creation of a quantum institute, development of space-based quantum networking testbeds, and sensor technologies for space applications. A more focused and forward-looking United States demonstrates its determination to strengthen its leadership in the global quantum race and drive substantial innovation and economic growth.

Quantum Technology Companies

According to The Quantum Insider Intelligence Platform, the United States accounts for approximately one third of the 1,350 global quantum companies being tracked (as of H1 2024). Of these 414 companies, more than 90% are private. The figure below shows the breakdown of companies by category.

The chart demonstrates the strength of the quantum supply chain in the United States, with 37% of firms producing hardware components. The quantum 'pillars' of communication and security, sensing, and computing are being established, as are firms developing quantum algorithms and software, and providing consultancy and education services. The growth of the quantum industry has been significantly supported by investment and entrepreneurial initiatives. There is a natural bias towards hardware development as that requires more funding.



The United States has a strong investor community to fund start-ups to scale-ups and beyond. Of the 457 quantum investors surveyed, venture capital firms dominate (264), followed by angel investors (53), corporate VCs (41), and family offices (19). This distribution is reflected in the number of investments made.

In total ~$4.2 billion has been invested in the USA from 210 funding rounds to date, with two-thirds of investments from venture capital firms, which demonstrates the strength of the USA's venture capital ecosystem compared to the rest of the world.

Regional and State Presence

While nations refine their quantum strategies, regional and state initiatives are emerging to develop their own quantum ecosystems and position themselves competitively as quantum hubs. By uniting efforts from grassroots organizations to political leaders, these

initiatives are establishing their quantum credentials to capitalize on the billions of dollars of estimated opportunity.

A comparison of the state of Tennessee with four other states developing their own quantum ecosystem is shown below.

Comparison of Quantum Ecosystems

	Tennessee	Colorado	California	Illinois	Massachusetts
Academia	• University of Tennessee, Knoxville • University of Tennessee, Chattanooga • Vanderbilt University	• University of Colorado Boulder (CU Boulder) • Colorado State University (CSU) • Colorado School of Mines	• University of California, Berkeley • Stanford University • California Institute of Technology University of California, Santa Barbara	• University of Illinois at Urbana-Champaign • Northwestern University • University of Chicago • University Illinois-Chicago	• Exceptionally strong academic base. Home to world renowned quantum researchers. • MIT, Harvard
Quantum Companies	• AlphaRail • Qubit Engineering • Qubitekk	• Infleqtion • Quantinuum • Atom Computing (20+ in total)	• QCWare • Rigetti • Psiquantum • Google • Microsoft	• QBraid • MemQ (20+ in total)	• Zapata AI • Quera • Atlantic Quantum (50+ including supply chain)
End Users	• Manufacturing • Healthcare • Finance • Telecoms • Logistics	• Mining • Defense and homeland security • Aerospace • Advanced manufacturing • Electronics	• Finance • Chemistry	• Finance • Biotech	• Chemistry • Biotech • Finance
Capital	• Some deep tech funds	• Several deep tech funds	• World's leading VC community	• Duality accelerator	• One University accelerator: the engine
Other Ecosystem	• Aerospace • Transportation Cybersecurity	• Metrology and sensing	• All tech, AI	• Fintech	• Chemistry • Cybersecurity
Strengths	• Oak Ridge National Lab • Strong university system statewide • Advanced fiber-optic network (EPB) • See full analysis later in report	• NIST; backing from state • Diverse quantum activities • Elevate Quantum Tech Hub ~$41 million in EDA funding	• Access to VC, access to big tech industries, quantum workforce Very diverse offering in quantum	• Strong academic backing Quantum activities at Argonne National Lab	• Strong academic backing • Diverse interests across quantum tech

Case Study 1: Colorado

Colorado has developed a robust ecosystem for quantum technology, driven by the presence of the National Institute of Standards and Technology (NIST) and several prominent universities. This environment has fostered the emergence of numerous spinouts and attracted a range of quantum technology companies. One notable achievement is the development of one of the world's first neutral atom quantum processors by Infleqtion.

The state is home to over 20 quantum companies, including homegrown initiatives and spinouts such as Honeywell Quantum Solutions (now Quantinuum, after merging with Cambridge Quantum). The region's expertise and infrastructure in quantum sensing and cold atom technologies have also attracted companies like Atom Computing and Maybell Quantum.

Colorado's quantum metrology facilities have significantly contributed to advancements in quantum sensing, computing, and security applications. The region has seen multiple

funding events over the past five years, indicating strong industry support and a vibrant community that effectively attracts investment.

The National Science Foundation is investing nearly $20 million to build the National Quantum Nanofab (NQN)[40] at the University of Colorado Boulder. Funded by the Mid-Scale Research Infrastructure 1 program, this open-access nanoscale fabrication facility will offer advanced quantum device fabrication, characterization, and packaging. It will also serve as an educational center and support workforce development initiatives.

Despite these successes, Colorado faces challenges related to limited human resources, which is a common challenge for all quantum ecosystems. The University of Colorado Boulder, the University of Colorado, Colorado Springs, and the Colorado School of Mines are key players in quantum-related education and research, yet there is a noticeable gap in the talent pool needed to sustain growth in this sector.

To address this, the University of Colorado Boulder hosts the Quantum Initiative, which brings together multidisciplinary researchers to collaborate on quantum projects. The University of Colorado Colorado Springs offers programs in quantum computing and quantum information science, while the Colorado School of Mines focuses on quantum materials and sensing. Expanding collaboration and investment in educational and workforce development initiatives across these institutions will be crucial to meeting the growing demands of the quantum technology industry.

Recently, the Governor of Colorado announced a $74 million investment plan[41] to strengthen the state's quantum ecosystem. This includes a refundable tax credit program aimed at enhancing Colorado's competitiveness in technology, with a particular focus on CU Boulder.

The U.S. Economic Development Administration (EDA) has designated Elevate Quantum as a quantum Tech Hub, awarding it approximately $41 million. This funding is further supported by contributions of $77 million from Colorado and $10 million from New Mexico. The EDA grant funds the following 3 projects:

1. Building open-access quantum labs and fabrication facilities for rapid prototyping and low-volume manufacturing of key quantum technologies.

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[40] *NSF Announces $20 Million Investment in Quantum Nanofabrication Infrastructure | NSF - National Science Foundation*. 20 June 2024, https://new.nsf.gov/news/nsf-announces-20-million-investment-quantum.

[41] Swayne, Matt. "State Leaders Announce Details of Legislation to Unlock >$1 billion in Funding to Colorado's Quantum Ecosystem." *The Quantum Insider*, 19 Feb. 2024, https://thequantuminsider.com/2024/02/19/state-leaders-announce-details-of-legislation-to-accelerate-colorados-quantum-ecosystem/.

2. Offering inclusive workforce development programs across educational institutions and companies to ensure a skilled and diverse regional talent pool.
3. Managing the consortium's strategy, stakeholder and investor engagement, and executive management to realize the Tech Hub's vision.

The Elevate Quantum coalition (over 70 organizations) works to establish a regional quantum tech hub, involving Wyoming and New Mexico, and emphasizes the importance of including EPSCoR states to democratize quantum technology access.

Case Study 2: Illinois

Illinois is rapidly advancing in the field of quantum technology through collaborative efforts among academic institutions, research facilities, industry leaders, and government agencies. Central to this progress is the Chicago Quantum Exchange (CQE), a consortium led by the University of Chicago, Argonne National Laboratory, Fermilab, and the University of Illinois at Urbana-Champaign. This hub promotes quantum information science and engineering, facilitating research, education, and workforce development. The CQE enables interdisciplinary collaborations and access to cutting-edge quantum research facilities.

The CQE's foundation includes key institutions such as Argonne National Laboratory, Fermi National Accelerator Laboratory, the University of Illinois Urbana-Champaign, the University of Wisconsin-Madison, and Northwestern University. With over 40 partners from corporate, international, non-profit, and regional sectors, the exchange drives innovation and economic growth through cross-sector partnerships.

The University of Chicago is pivotal in Illinois's quantum landscape, hosting a distinguished group of scientists and engineers. The university's Pritzker School of Molecular Engineering offers one of the first doctoral programs in quantum science and engineering, supported by federal grants and industry partnerships. This program prepares students for the challenges and opportunities in quantum technology.

Illinois's quantum initiatives have received substantial support. In February 2024, Governor JB Pritzker proposed a $500 million budget[42]allocation for quantum technologies to strengthen the regional quantum ecosystem and maintain U.S. leadership in the field. The proposal includes $200 million for a cryogenic facility and

[42] "Governor JB Pritzker Announces Historic $500 Million Investment Aligning with the CHIPS and Science Act." *Yahoo Finance*, 26 Feb. 2024, https://finance.yahoo.com/news/governor-jb-pritzker-announces-historic-223700888.html.

$100 million for a quantum campus, to secure CHIPS and Science act funding, and attract major quantum computing companies to the area. For instance, the photonics quantum computing firm PsiQuantum is considering two potential sites for a state-of-the-art quantum computing facility: the 440-acre former U.S. Steel South Works on Chicago's South Side and the former Texaco refinery in Lockport.

Significant investments have been made in Illinois's quantum sector, highlighted by $280 million from the 2018 National Quantum Initiative Act and a combined $150 million from IBM and Google to the University of Chicago and the University of Tokyo. These funding efforts underscore the growing confidence in Illinois's quantum technology initiatives.

Case Study 3: California

California's quantum technology sector benefits from contributions by large companies, start-ups, venture capital firms, and research institutions. Key quantum hubs are spread across the San Francisco Bay Area, Los Angeles, and San Diego. These regions, known for their concentration of tech companies and research institutions, foster collaboration, and innovation within the quantum technology community.

Silicon Valley, located in the San Francisco Bay Area, thrives on a strong venture capital investment network and a large technical talent pool. Major technology companies in California are developing quantum capabilities, often in partnership with start-ups, universities, and government agencies. For example, Google has collaborated with NASA and the Universities Space Research Association to establish the Quantum Artificial Intelligence Lab in Santa Barbara, where they house the first quantum computer to demonstrate capabilities beyond classical computation. Nvidia and Fujitsu also have significant quantum operations in the state.

California hosts several leading universities and research centers with advanced quantum research and development programs. These include UC Berkeley, Stanford, the California Institute of Technology (Caltech), Berkeley Lab, and the University of Southern California (USC), which was one of the first universities[43] to host a D-Wave quantum annealer. Stanford's SLAC National Accelerator Laboratory and Caltech, home to Amazon's quantum computing center, are notable contributors. Berkeley Lab and UC Berkeley host the DOE-funded Advanced Quantum Testbed (AQT)[44], providing

[43] "USC ISI Works with D-Wave to House One of the First U.S-Based Advantage Quantum Computers." *USC Viterbi | School of Engineering*, https://viterbischool.usc.edu/news/2022/05/usc-isi-works-with-d-wave-to-house-one-of-the-first-u-s-based-advantage-quantum-computer/.
[44] "Home Page." *AQT*, https://aqt.lbl.gov

advanced superconducting infrastructure for full-stack quantum computing to the research community.

The state's vibrant start-up culture and access to robust venture capital have led to the proliferation of quantum technology start-ups, such as PsiQuantum and QCI for hardware, and QCWare for software. Additionally, the Canadian company D-Wave has partially relocated its operations from Vancouver to California, highlighting the state's favorable environment for quantum computing activities.

Case Study 4: Massachusetts

Massachusetts is a global hub for quantum technology, hosting over 130 research groups across 15 universities that explore a wide range of quantum technologies, including quantum sensing, quantum matter, and quantum photonics, with significant implications for quantum computing. Harvard and MIT, through their Quantum Initiative efforts, lead this research, supported by a network of over 100 senior academics. Additionally, Boston University and other universities are actively engaged in quantum technology research, making Massachusetts a leader in this innovative field. Notable institutions like Lincoln Lab and the Amazon Web Services Center for Quantum Networking[45] further enhance the state's prominence in quantum research.

The MassTech Innovation Institute has made significant investments in quantum infrastructure at colleges and universities. In April 2022, the institute allocated $1 million[46] to enhance quantum R&D facilities at UMass Boston and Western New England University (WNEU) in Springfield. In September 2022, Northeastern University received a $3.5 million grant[47] for its Experiential Quantum Advancement Laboratories (EQUAL). These investments underscore the state's commitment to advancing quantum technologies.

Massachusetts's quantum ecosystem includes a diverse array of stakeholders, such as research centers and companies dedicated to quantum computing and related

[45] *Announcing the Opening of the AWS Center for Quantum Computing | AWS Quantum Technologies Blog*. 26 Oct. 2021, https://aws.amazon.com/blogs/quantum-computing/announcing-the-opening-of-the-aws-center-for-quantum-computing/.

[46] *Baker-Polito Administration Awards $1 Million for New UMass Boston Quantum Computing R&D Facility | MassTech*. https://masstech.org/news/baker-polito-administration-awards-1-million-new-umass-boston-quantum-computing-rd-facility.

[47] *Baker-Polito Administration Awards $3.5 Million R&D Grant for New Northeastern University Quantum Facility | MassTech*. https://masstech.org/news/baker-polito-administration-awards-35-million-rd-grant-new-northeastern-university-quantum.

technologies. The state hosts approximately 50 companies, ranging from startups to large enterprises, focusing on quantum computing. Massachusetts is home to multiple quantum computer producers, particularly in cold atom (e.g., QuEra) and superconducting qubit technologies (e.g., Atlantic Quantum), demonstrating its commitment to quantum advancement.

The state also hosts a vibrant photonics ecosystem, with companies and research groups engaged in photonics research, further supporting quantum activities. Massachusetts's robust infrastructure and networks make it an attractive entry point for North American markets, drawing significant private investment. This growing sub-ecosystem is highlighted by the rise of corporate entities facilitating quantum technology transfer and increasing job opportunities in the field.

As a hub for international conferences, Massachusetts offers extensive networking opportunities and attracts leading researchers. There are promising avenues for growth, including the formation of private companies from academic spinouts and the exploration of quantum sensing applications. At the core of this ecosystem is a strong academic foundation, with Massachusetts universities playing a crucial role in driving research, nurturing talent, and training the quantum workforce.

Lessons Learned from Other States

	Colorado	California	Illinois	Massachusetts
Lessons	• Leverage existing expertise and infrastructure to attract new quantum companies • Strong industry support accelerates ecosystem growth • Strategic investments drive ecosystem development • Involving diverse stakeholders promotes broader ecosystem growth	• Diverse contributors drive the quantum landscape • Geographical hubs foster collaboration • Silicon Valley's VC network fuels quantum innovation • Collaboration accelerates quantum capabilities	• Collaborative efforts drive quantum momentum • Strategic investments boost research and workforce • Competition for federal funding can accelerate progress. • Anchor institutions amplify Illinois's quantum ecosystem	• Leading research institutions drive quantum innovation. • Innovation hubs spur IP creation • Startups, especially from universities, boost ecosystem dynamism • Diverse tech ecosystem fosters cross-industry growth • Collaborative research accelerates quantum progress

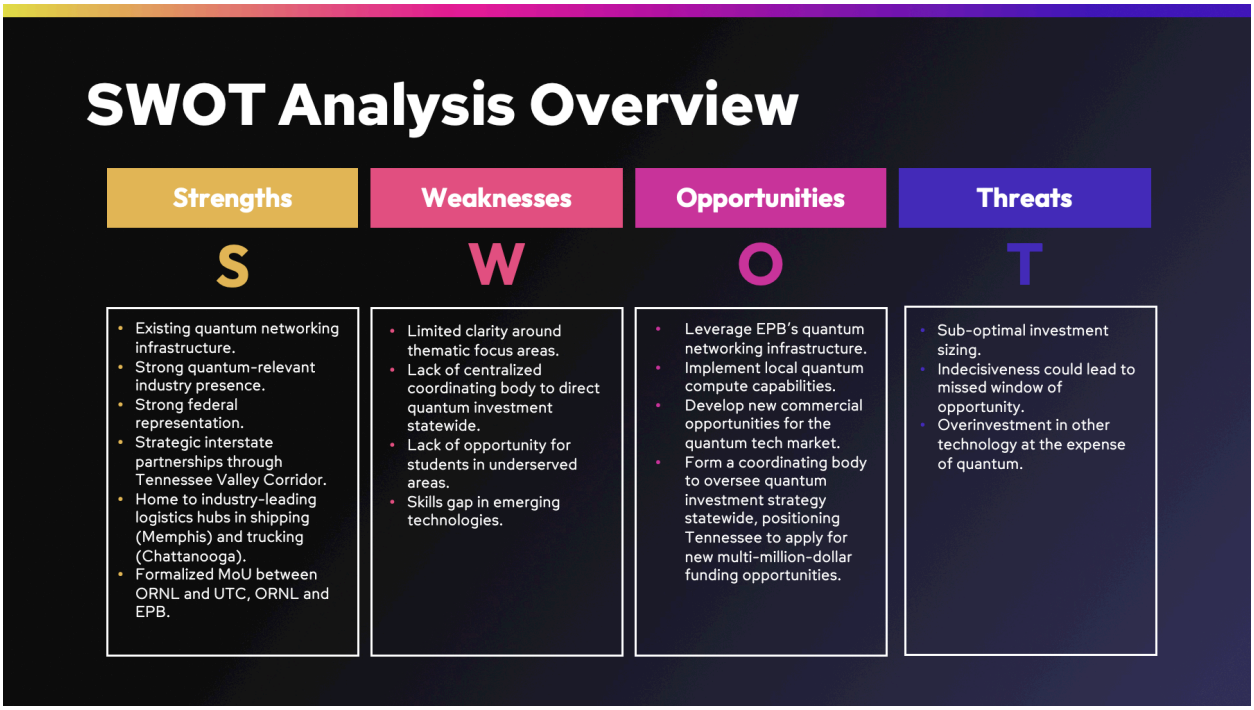
Key Lessons

Building a state-led quantum ecosystem requires a multifaceted approach incorporating lessons gleaned from the case studies, including:

- **Encourage collaboration:** different kinds of collaborations are required: partnerships between universities and industry to accelerate R&D can bridge the gap between research and market applications, leveraging interdisciplinary research to expand innovation. Successful collaborations can increase access to quantum devices, catalyze application development, and grow a user community.
- **Academic leadership:** universities have a key role to drive research innovation, develop and coordinate quantum initiatives, and commercialize research outputs to benefit the economy and wider society.
- **Workforce development:** developing accredited quantum educational programs and workforce training initiatives builds a sustainable talent pipeline and the next generation of quantum scientists and engineers.
- **Entrepreneurship & investment**: encouraging entrepreneurship and attracting strong venture capital for quantum technology start-ups are both key to driving innovation and economic growth.
- **Regional hub:** establishing a regional hub of expertise supported by funding, infrastructure and resources, results in a more resilient quantum ecosystem.
- **Quantum identity:** playing to one's strengths in quantum technology development and understanding the gaps help shape a unique quantum strategy and prioritise effort.

  End-users: engaging end-users is critical to aligning quantum technology development to market needs and driving practical applications and adoption.

SWOT Analysis



Strengths

> *Chattanooga is known as **the Silicon Valley of logistics**. The CEOs of the logistics companies will say I want to start applying this quantum computing to my trucking data, [because] if I could maximize the space and every truck 18-Wheeler in the United States I could take half of them off the road for a giant carbon reduction and half a trillion dollars in productivity gains...*
>
> *- Vice President, Local Public Utility*

> *...**The university** has started a quantum center. They've **invested $3m of their own money (in quantum) and received NIST funding for an additional $3m**. They have been able to attract a couple of different quantum researchers that otherwise would not even have looked twice at Chattanooga.*
>
> *- Senior Executive, Local Public Utility*

> *...We have the **Department of Defence** come in to do work here, we have a relationship with the **Department of Commerce** through NIST, and we have a relationship with the **Department of Energy** through the Oak Ridge National Laboratory.*
>
> *- Vice President, Local Public Utility*

- **Existing quantum networking infrastructure:** Chattanooga boasts the country's first commercially available, professionally managed quantum network. In partnership with Qubitekk, the Electric Power Board of Chattanooga successfully expanded the capabilities of its existing fiber-optic cable infrastructure to create the EPB Quantum Network, propelling Chattanooga to the fore of the quantum technology ecosystem in the US. Established companies,

startups, small-to-mid-sized enterprises, as well as independent and federally funded research groups are all prospective EPB Quantum Network users, and the network is already being utilized effectively. Onboarding and recruiting processes are already in place for new users, who can purchase short-term or long-term network "nodes."

- **Strong quantum-relevant industry presence:** Tennessee is a national leader in several industries relevant to quantum technologies, including logistics & supply-chain management, biomedical research, nuclear energy research, and advanced electric power distribution technology and is rapidly expanding its capabilities in emerging fields like electric vehicle manufacturing.

  Tennessee has a strong presence in transportation/logistics that extends far beyond FedEx's global headquarters in Memphis. In fact, the Chattanooga area has been dubbed the "Silicon Valley of Freight," due to the cluster of freight transportation/logistics firms and support services based in the area. Players include U.S. Xpress, Covenant Transport, market intelligence provider FreightWaves, and several freight brokerage firms born from asset-based players or early movers Access America that sold to Coyote Logistics which later was acquired by UPS. With quantum computing's potential to optimize complex processes, freight carriers and brokers could reap significant benefits by being early testers and adopters of quantum technology.

- **Strong federal representation:** Tennessee's federal leadership can have a positive impact on the region's development of a quantum-ready ecosystem. U.S. Congressman Chuck Fleischmann TN-3, serves as Chairman of the House Appropriations Subcommittee on Energy and Water Development, overseeing funding for critical energy and scientific research initiatives. U.S. Senator Marsha Blackburn, a member of the Senate Commerce Committee, has been instrumental in advancing quantum technology legislation. She co-introduced the Defense Quantum Acceleration Act, aiming to enhance the Department of Defense's quantum capabilities. U.S. Senator Bill Hagerty's role on the Senate Appropriations Committee positions him to influence legislative processes & funding that can support technological advancements. U.S. Congressman Mark Green TN-6, serves as Chairman of the House Homeland Security Committee, overseeing national security initiatives including quantum technology development, their strategic positions and active support for quantum initiatives

provide East Tennessee with a robust foundation to cultivate a quantum technology ecosystem.

- **Interconnected initiatives along strategic TVC corridor:** The Tennessee Valley Corridor (TVC), which works across 13 contiguous congressional districts in 5 states to promote the TVC's national leadership in science and technology, has a mission to sustain existing federal missions in the Tennessee Valley Corridor, attract new federal investment, and leverage investment for private-sector job creation – a mission that provides a strong foundation for future quantum technology investment. Tennessee, along with the four neighboring states that are also part of the TVC – Kentucky, Alabama, North Carolina, and Virginia – have undertaken ambitious past initiatives in the areas of space exploration, national security, and environmental technology; the corridor is thus well positioned to bring its organizational leadership to bear on quantum technologies.

- **Establishment of Collaborative for Energy Resilience and Quantum Science (CERQS) by EPB and ORNL:** In January 2024, EPB and ORNL announced the creation of CERQS, a joint initiative leveraging Chattanooga's advanced energy and communications infrastructure. This collaboration builds on over $180 million in shared research and focuses on enhancing the resilience and security of the national power grid while advancing the commercialization of quantum technologies.
- **Formalized Memorandum of Understanding (MoU) between UTC and ORNL:** In August 2024 UTC and ORNL formally agreed to extend and deepen their collaboration on quantum information science and engineering (QISE), focusing on networking, sensing, and computing research while simultaneously integrating new opportunities into the UTC curriculum including capstone projects and internships. The five-year MoU establishes focus areas in material development, secure quantum networks, and advanced hybrid quantum computing.
- **Chattanooga civic spirit and testing capabilities**: Chattanooga's strong civic spirit is a significant asset, enabling effective testing and implementation of innovative technologies.

"I have been so impressed with Chattanooga's ability to open their arms and contribute to the success of others. Our corporate partners are that way, and the community is that way. I mean people are just willing to help other people here"- TN Investor

The city's community-oriented approach and support for public-private partnerships creates an environment conducive to experimentation with cutting-edge technologies. such as the smart grid. The city's cooperative spirit fosters a proactive stance towards embracing technological advancements along with understanding from senior leaders on the promise of quantum technology.

- **Attractive economic environment and strategic location**: Tennessee's favorable economic environment is characterized by competitive tax policies, business incentives, and a cost-effective living and operating environment. The state's pro-business policies and regulatory framework attract both established businesses and start-ups.

"We were a dying Rust Belt city in the south. We were losing population in the 70s and 80s. There was a significant focus by the private sector and private sector leadership and philanthropy around reinvesting in the community rebuilding our manufacturing base rebuilding our downtown."
– Chattanooga Chamber of Commerce

This economic vibrancy is bolstered by the state's strategic location, providing access to major markets in the Southeast and beyond. Its central location in the United States, combined with its robust logistics infrastructure, including major highways, railroads, and the Memphis International Airport (a major cargo hub), makes it an ideal location for businesses that rely on efficient supply chains and distribution networks.

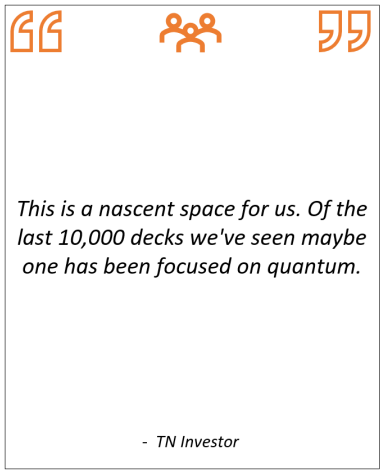
- **Existing technological assets:** Tennessee is home to significant technological and research assets such as the EPB Quantum Network in Chattanooga and the Oak Ridge National Laboratory (ORNL).

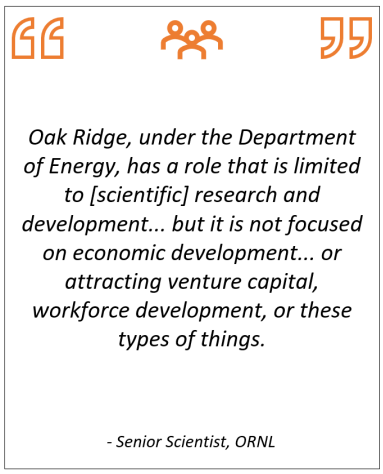
"When EPB laid out fiber capacity back in 2010.... they started to operate internally more like a telecommunications company than an electricity distributor. And I think seeing the world through that lens for EPB made them think about what is next." – Chattanooga Chamber of Commerce

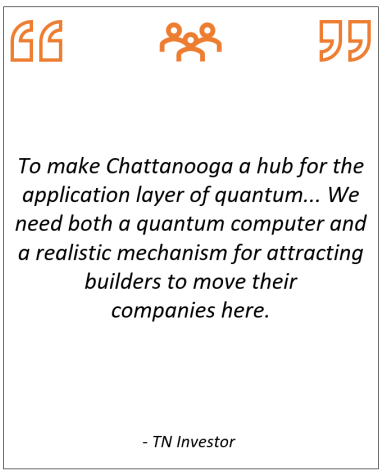
These institutions provide state-of-the-art infrastructure and resources for scientific research and technological innovation. For example, ORNL, as a multi-disciplinary research facility, offers extensive capacity in quantum computing, material science, and advanced manufacturing, positioning Tennessee as a leader in these fields. Its contacts within those federal agencies to help tailor the state's quantum technology investments to meet the goals set forth by the federal government around national security, energy production & sustainability, and cybersecurity.

- **Existing academic assets:** A Governor's Chair academic position has been awarded to UTC as a part of ongoing Quantum Information Science and Engineering (QISE) program, operated at the UTC Quantum Center and funded by the US Department of Commerce through the National Institute for Standards and Technology (NIST). The search to fill the UTC Governor's Chair in Quantum Information Science and Engineering position is active for the upcoming academic year. The position will focus on innovative R&D in addition to expanding the emerging quantum ecosystem in Chattanooga.
- **Quality of life:** Tennessee offers a high quality of life, with affordable housing, vibrant cultural scenes, and a favorable climate. Cities like Nashville and Chattanooga are known for their music, arts, and outdoor recreational opportunities, which attract talent and contribute to a vibrant community life.

Weaknesses







- **Limited clarity around thematic focus areas**: Tennessee has not narrowed its thematic investment focus areas to cohere in a meaningful strategy, and as a result its investments to-date have overdiversified to the point of over-dilution across multiple large but non-overlapping initiatives. Quantum risks becoming yet another one of those initiatives, drawing investment dollars away from one or another alternative technology development area which promises to be paradigm changing. Therefore, Tennessee needs to avoid trying to do too much too soon with quantum, and instead target a realistic and achievable quantum initiative in which to invest, preferably one that dovetails with an existing initiative around other key investment areas like mobility or nuclear energy.
- **Lack of centralized coordinating body to direct quantum investment statewide:** Despite promising initial forays into quantum technology innovation in Tennessee, the lack of a clearly articulated vision, with clear objectives, has limited Tennessee's ability to strategically grow its quantum ecosystem statewide. To secure federal funds allocated for quantum technology investment Tennessee must have a responsible body to apply for and administer those funds, and to make the case that Tennessee is the best recipient, keeping in mind the competition from other states. To distinguish itself in applications for federal funds Tennessee needs a centralized body overseeing quantum activity across the state to clearly articulate the differentiated value proposition for federal quantum investment in the state.
- **Lack of opportunity for students in underserved areas:** To generate long-term, sustainable growth for quantum in Tennessee it will be important to

distribute opportunities equitably throughout the state, including in rural areas. While urban centers like Nashville and Chattanooga thrive, many rural areas lag.

"We are trying to get a better sense of what it [the next iteration of quantum] means for the average citizen in our community, both from the economic development standpoint… and from the real benefits standpoint. How do we communicate that… not only to taxpayers and organizations but to broader swaths of the community?" – TN State Government Leader

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Though not unique to Tennessee, this could be a long-term restriction on statewide progress and equitable growth. Practically speaking, it will also require careful stakeholder management, ensuring that the future benefit of any investment is well understood by the broader population.

- **Skill gaps in emerging technologies**: While Tennessee has a strong manufacturing base, there are skill gaps in emerging technologies such as quantum computing, AI, and advanced materials. Addressing these gaps requires targeted educational and training programs to build a workforce equipped for the demands of the future economy.

Opportunities

*I go back to trying to **tie quantum in with other initiatives where it can be a part of the solution.** That's a first step to get that long play…you're demonstrating the value of partnership when it's **collaborating with other important initiatives***

- Senior Official, Tennessee State Government

*With our small reactors we are starting to ask… **could we do large scale simulations (with quantum) …to solve key problems in modelling nuclear reactions, like neutron diffusion?***

- Section Lead, Oak Ridge National Labs

*Volkswagen is making an expansion in Chattanooga… they're relocating engineers on the order of hundreds… and **they have a keen interest in quantum technology.** They want to send engineers here to figure out some of the problems they have on the factory floor.*

- Senior Administrator, UTC

- **Leverage EPB's quantum networking infrastructure:** Chattanooga has already drawn interest from new quantum companies based in other states – like Qunnect – looking to evaluate their products on Tennessee's extensive infrastructure. As EPB Quantum Network continues to attract companies to use its infrastructure, EPB could

multiply the value it provides to each network user while situating itself as a center of quantum networking activity.

- **Implement local quantum compute capabilities:** There is a clear opportunity to install and operate a quantum computer locally in the eastern Tennessee region, given the proximity of existing EPB Quantum Networking infrastructure. A commercially available, publicly owned (and/or available for use) quantum computer housed and operated in eastern Tennessee would help translate the research & development activity in quantum and quantum-adjacent technologies taking place at ORNL and UTC into commercial activity that bolsters the regional economy, thereby ensuring that future scientific breakthroughs in the field result in tangible benefits to the community.
- **Develop new commercial opportunities for the quantum technology market:** The recent announcement of IonQ's plans to acquire Qubitekk presents a significant opportunity for East Tennessee's quantum ecosystem. Qubitekk, which already has a presence in Chattanooga, specializes in quantum network hardware and solutions. If the acquisition proceeds as planned, Tennessee stands to benefit from the elevated presence of IonQ, a globally recognized, publicly traded leader in quantum computing. This development would position the region as a key hub for advancements in distributed quantum computing, leveraging IonQ's cutting-edge technologies and Qubitekk's local expertise, enhancing Tennessee's role in the rapidly advancing quantum technology landscape.

"With IonQ's interest in the quantum network in Chattanooga, we would like to start engaging more companies to do the same. If we can ever get one of them to come down and commit to putting two computers on the network and connecting them together to show that you can build a bigger computer from two smaller ones, I think it's going to be a major milestone
for the industry."
– TN Industry Stakeholder

- **Position Tennessee for future multi-million-dollar quantum funding opportunities:** There is a window of opportunity for Tennessee to position itself to win future quantum funding from the federal government, private industry, and potentially international partners if it continues to make strategic, early-stage

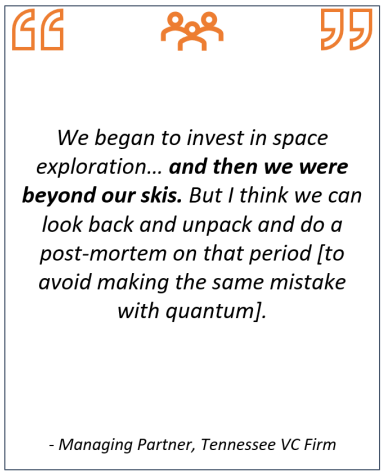
investments in quantum technology through organizations like the Chattanooga Quantum Collaborative. Given the importance of a centralized coordinating body to organize partnerships and secure funding for quantum investment in Tennessee, having an organization already in place to spearhead such efforts (i.e., the CQC) is a strength that the state should look to leverage, potentially by forming a "Tennessee Quantum Collaborative" to serve as an umbrella organization over other regional quantum collaboratives (CQC among potential others) within the state, if there were sufficient interest in creating that structure.

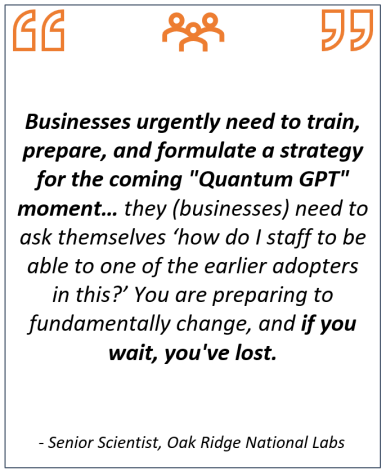
A central body responsible for coordinating quantum investment efforts across Tennessee would be the ideal structure to apply for and secure future federal quantum funding. A central coordinating body could speak to how investment dollars would expand access and develop the economy statewide, as opposed to limiting applications to region-specific use-cases.

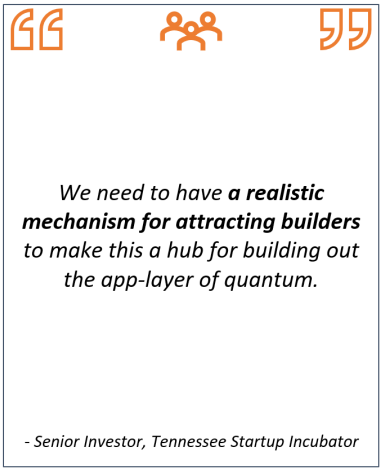
- **Append quantum investment to other tech investment initiatives:** Although it may be premature to seek large-scale investment specifically for quantum, it is more realistic to consider opportunities for quantum to supplement other investment initiatives – nuclear, AI – which have already garnered statewide investment support. For example, as existing investments mature in fields like nuclear and AI, the underlying demand for electricity has proven to be a rate-limiting factor inhibiting their growth. Quantum does not need to – nor should it – compete with nuclear and AI for funding in Tennessee; on the contrary quantum should seek to be a complementary or supplementary add-on to ongoing nuclear, AI data processing, or other electricity-intensive initiative that the state may want to engage in, such as the Orano Uranium Enrichment Facility at ORNL, which is set to begin production in 2030.
- **Become a national leader in quantum applications:** There is a clear opportunity for Tennessee to take a national leadership role in rolling out use cases for future quantum technologies. This could take the form of an applications program focused on addressing critical technological and societal issues through quantum solutions, leveraging its existing assets and fostering collaboration among academia, industry, and government.
- **Form a Southeastern US Quantum Initiative:** Advanced quantum investment is already underway in two neighboring states, providing the foundation for interstate collaboration and partnership. South Carolina founded the South Carolina Quantum Association in 2022 with the intent of promoting collaboration between academia,

industry, and government to advance quantum information science and technology. Georgia Tech and Huntsville, Alabama have also recently launched their own quantum initiatives. Their efforts are currently focused on implementing small quantum algorithms into quantum sensors. Proximity to ongoing quantum research offers avenues for near-term partnership and collaboration with neighboring states, potentially reducing the amount of up-front investment required directly by Tennessee, thus de-risking the approach and potentially leading to better outcomes.

Threats







- **Sub-optimal investment sizing.** Tennessee's willingness to make big bets investing in new state industries has the potential to become a threat if Tennessee foregoes its competitive advantages in pursuit of undisciplined investments across disparate areas within quantum technology. Tennessee may wish to consider where it focuses it energy; instead of seeking to become a national leader in building quantum computers, for example, investment may be better focused on the application end of the value chain. Other states and countries already have the capability (through partnerships with their universities and the federal government) to build quantum computers. To replicate their success would require outsized up-front investment and would not generate returns in a reasonable amount of time for a new entrant to the field.
- **Indecision could lead to a missed window of opportunity.** The optimal time to invest in quantum technology precedes the optimal time for businesses to purchase and use quantum technology to meet their business goals. The threat is that Tennessee would decide (passively) to forego investment in quantum while waiting to see how the field matures, and in so doing miss a fleeting window of

opportunity to become an early adopter of a critical new technology before it commercializes. If the technology's promises materialize, the potential upside to being an established member of the ecosystem before demand increases nationwide and globally could be significant. Tennessee risks missing an opportunity to be a first mover in quantum for which it is already well positioned. The opportunity costs of excessive deliberation and delay must be accounted for.

- **Overinvestment in other technology at the expense of quantum.** Tennessee has already made significant investment in non-quantum technologies – nuclear, space, AI, aerospace & defense – which could reduce the overall appetite amongst investors to, from their perspective, add another risky and expensive technology to their portfolios. Viewed in such a light, quantum risks being overshadowed by investments in other areas of technological innovation in Tennessee.

Recommendations

1. Establish a clear leadership institution.

Objective: Create an organization to define, drive, and manage the ambitious vision, program, and execution plan for Chattanooga and/or the broader Tennessee region.

Actions:

- Designate a leading institution responsible for overseeing quantum ecosystem development.
- Secure initial funding from city, state, and federal sources, alongside contributions from key stakeholders like EPB, TVA, and private enterprises (e.g., Volkswagen).
- Ensure this institution can act swiftly, make informed decisions, and take calculated risks.
- Further detail on this was provided under separate cover to Chattanooga Quantum Collaborative.

2. Leverage existing assets and partnerships.

Objective: Maximize the potential of current assets and partnerships to support the development of Chattanooga's quantum ecosystem.

Actions:

EPB Quantum Network:

- Capitalize on the existing EPB Quantum Network and continue to increase usage/occupancy through focused programming
- Focus on unique commercial uses of the quantum network and seek to attract more research and commercial testing.

Oak Ridge National Lab (ORNL):

- Treat ORNL as a critical partner, leveraging its resources for testing and research.
- Monitor and participate in ORNL's evolving funding and project opportunities under the US National Quantum Initiative Reauthorization.
- Utilize the Collaborative for Energy Resilience and Quantum Science (CERQS) partnership to bolster regional quantum initiatives.

Tennessee Valley Authority (TVA):

- Map out critical potential use cases for TVA.

- Set up initial testbeds for practical deployment of quantum technologies.

3. Develop a comprehensive technology and workforce program.

Objective: Establish a robust technology and workforce development program to support the growth of the quantum ecosystem in Chattanooga.

Actions:

- Engage local universities, particularly UTC, to expand faculty and research capabilities in quantum science.
- Promote workforce training programs that prepare IT professionals to support and maintain quantum technologies.
- Encourage early-stage education and community awareness to build a robust pipeline of quantum professionals.
- Attract and support quantum-related startups by leveraging Chattanooga's tax benefits and resources.
- Focus on practical applications and use cases that align with Tennessee's industrial strengths (e.g., manufacturing, logistics, automotive).
- Collaborate with large enterprises and public utilities to identify and pilot quantum technology applications.

4. Foster regional and statewide collaboration.

Objective: Promote collaboration between Chattanooga and other cities within Tennessee, as well as with neighboring states, to build a cohesive quantum ecosystem.

Actions:

- Promote cooperative efforts between Chattanooga, Knoxville, and other Tennessee cities to create a unified state-wide quantum ecosystem.
- Identify and engage with additional research groups and quantum enterprise users across Tennessee.
- Explore partnerships and collaborative projects with neighboring states, particularly those with existing quantum initiatives.
- Position Chattanooga within a broader southeastern quantum corridor, enhancing its attractiveness to investors and talent.

5. Secure and manage funding commitments.

Objective: Develop a sustainable funding strategy to support the growth and development of Chattanooga's quantum ecosystem.

Actions:

- Develop a detailed funding strategy to secure $1-5 million from each key stakeholder (e.g., EPB, TVA, enterprises, donors).
- Allocate funds to projects that demonstrate immediate community and economic benefits, ensuring accountability and transparency.

6. Develop and execute a strategic roadmap.

Objective: Create and implement a strategic roadmap that outlines short-term and long-term goals for Chattanooga's quantum ecosystem.

Actions:

- Draft a comprehensive roadmap outlining short-term and long-term goals for the quantum ecosystem.
- Ensure the roadmap includes milestones for technology deployment, workforce development, corporate partnerships, and community engagement.
- Commit to regularly review and adjust the roadmap based on progress, new opportunities, and stakeholder feedback.

7. Engage stakeholders and drive community support.

Objective: Foster community support and engage stakeholders to ensure broad-based backing for Chattanooga's quantum initiatives.

Actions:

- Foster a strong civic spirit by involving residents and businesses in quantum initiatives.
- Communicate the long-term benefits of quantum technology, emphasizing potential economic growth and job creation.
- Create platforms for ongoing dialogue and collaboration among all stakeholders, ensuring broad-based support for the ecosystem.

Glossary

DOD: Department of Defense

DOE: Department of Energy

EPSCoR: Established Program to Stimulate Competitive Research.

ESIX: Subcommittee on Economic and Security Implications of Quantum Science

NASA: National Aeronautics and Space Administration

NDAA: National Defense Authorization Act

NQCO: National Quantum Coordination Office

NQI: National Quantum Initiative

NQIAC: National Quantum Initiative Advisory Committee

NSF: National Science Foundation

NSTC: National Science and Technology Council

OSTP: Office of Science and Technology Policy

QED-C: Quantum Economic Development Consortium

QIS: Quantum Information Science

QIST: Quantum Information Science and Technology

QLCI: Quantum Leap Challenge Institute

QPU: Quantum Processing Unit

R&D: Research and Development

SCQIS: Subcommittee on Quantum Information Science

STEM: Science Technology Engineering and Mathematics

Appendix

About Chattanooga Quantum Collaborative

The Chattanooga Quantum Collaborative (CQC) is a non-profit organization dedicated to establishing a robust quantum ecosystem in Chattanooga, Hamilton County, Tennessee, and beyond. By leveraging quantum resources and mobilizing diverse partnerships for the benefit of the region's people, businesses, and communities, the CQC aims to drive workforce development, economic growth, and technology advancement in the quantum sector. For more information about the Chattanooga Quantum Collaborative, visit www.ChattanoogaQuantum.com.

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