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CHICAGOLAND'S QUANTUM ECOSYSTEM

WORLD BUSINESS CHICAGO | THE RESEARCH CENTER

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Executive Summary

Chicago is not Silicon Valley: our uniqueness lies in fostering a distinct and diverse technological ecosystem, where the collective business community carves out its own path to innovation. Chicago's advantage lies in its diverse range of industries, which span finance, healthcare, manufacturing, and more. This diversity allows for cross-pollination of ideas, especially as quantum companies collaborate with various industry sectors, leading to innovative solutions that cater to specific, real-world challenges. Chicago's rare environment enables rapid commercialization and practical application of quantum technologies.

In this issue of the Chicago Business Bulletin, the World Business Chicago Research Center will illustrate Chicagoland's advantages in the quantum industry across a number of metrics, including its diverse industrial base, but also academic and research institutions, private and public investments, and intellectual property production.

Findings:

- **Chicago's diverse industry base creates a wealth of real-world challenges and applications for quantum companies to address.** Chicago is one of the top metro areas in the US for industries — like high tech, IT-producing, and IT-using industries — that most often acquire new technology as part of their innovation strategies.

- **Within the US, the broader Chicago region (including the Chicago, Urbana-Champaign, and Madison, Wisconsin metro areas) has the third highest number of universities engaged in quantum research activities.** With respect to actual academic programs, this region has the **third** most universities with quantum-related academic program completions.

- Global investment in quantum startups has increased dramatically since 2020; Illinois is a leader in US-based investments. **Illinois has the second most deals made by quantum startups after California.** Investment in Illinois and Midwestern quantum startups is more likely to be captured by software-focused firms, compared to hardware-focused firms.

- **Illinois has a diverse, well-balanced distribution of quantum patents across sub-niches, especially compared to other high-performing states with significant quantum presences.** Notably, 47.8% of Illinois' quantum patents fall under quantum devices, while 14.5% are in quantum optics and quantum information processing. In contrast, California — the largest quantum patent producer — has over 70% of its patents in quantum devices and only 5% in quantum optics and quantum information processing.

Defining Quantum

Quantum computing's distinct power exploits properties unavailable to classical computers.

McKinsey & Company defines quantum computing as a rapidly-emerging form of technology utilizing principles of fundamental physics to efficiently solve complex statistical problems that today's computers are unable to. Quantum computers can narrow the range of possible solutions to a finance or logistics problem, helping a company reach the best solution faster.

Industries that stand to benefit the most from quantum computing include:

- **Pharmaceuticals:** Quantum computing has the potential to revolutionize the R&D of molecular structures in the biopharmaceuticals industry.
- **Chemicals:** Quantum computing could be used to improve catalyst design, potentially enabling the replacement of petrochemicals with more sustainable feedstock or to minimize carbon usage.
- **Automotive:** The industry could benefit from quantum computing when it comes to R&D, product design, supply chain management, production and mobility, and traffic management.
- **Finance:** Long-term quantum computing implementation will be focused in portfolio and risk management.

McKinsey's analysis states that though the commercial application of quantum computing is still years away, other quantum technologies could become available much earlier:

- **Quantum computing**: A new approach to calculation that uses principles of fundamental physics to solve extremely complex problems.
- **Quantum communication**: Designed to transfer encoded quantum information between distant locations through a quantum-communication network.
- **Quantum sensing**: Quantum sensors can measure different physical properties, including temperature, magnetic field, and rotation with extreme sensitivity.

Why is quantum technology important for Chicagoland's economy?

The quantum revolution would have a significant impact on total factor productivity (TFP) and hence, overall productivity, which will ultimately lead to higher economic output — similar to the impact of technological advancements throughout economic history. As defined by the US Bureau of Labor Statistics, total factor productivity is measured as the ratio of aggregate output (gross domestic product) to aggregate inputs.

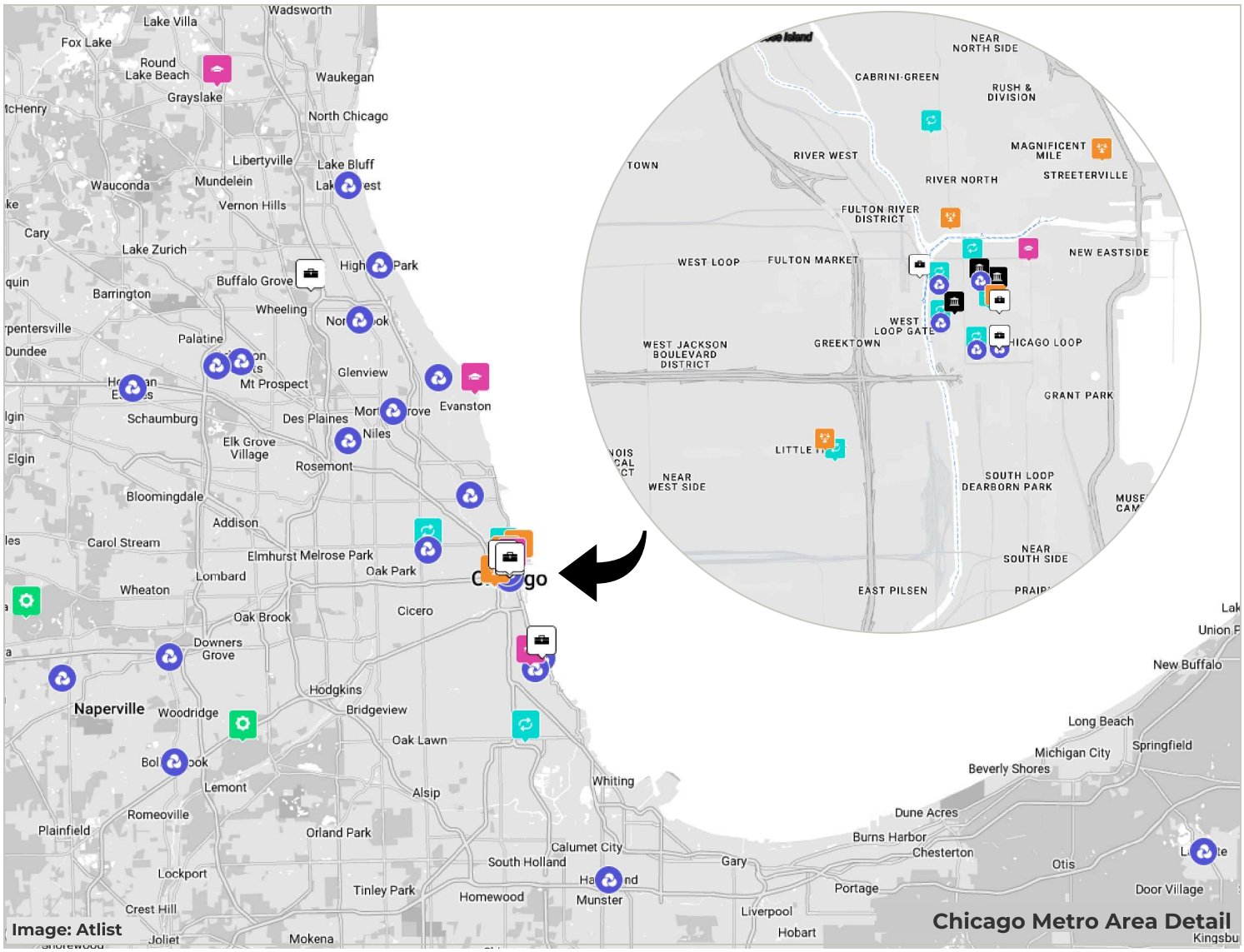
In fact, while TFP is considered the primary contributor to economic growth rates, technology growth and greater efficiency are among its most significant There is no better example of technology growth than the potential of the quantum revolution; it should lead to higher economic growth rates for Chicagoland than would be otherwise, without the region possessing competitive advantages for the quantum industry.

Increased economic productivity translates to economic prosperity for the region — including more quality jobs and wages — through higher revenues, investment, exports, and more.

Illinois' Quantum Ecosystem

Chicagoland's quantum ecosystem is broad, and includes **over 30 quantum companies and more than 40 corporate, government, academic, and non-profit partners**.

Chicagoland's quantum industry is regional. Participants in the quantum industry are concentrated in several different areas, chief among them Chicago's South Side, where the University of Chicago and the Chicago Quantum Exchange are located. Quantum companies are also located in Chicago's North and Northwest suburbs, as well as the city of Chicago's Loop and Central Area.



National Labs

Corporate Partners

Quantum Companies

Educational Partners and Institutions

Government Partners

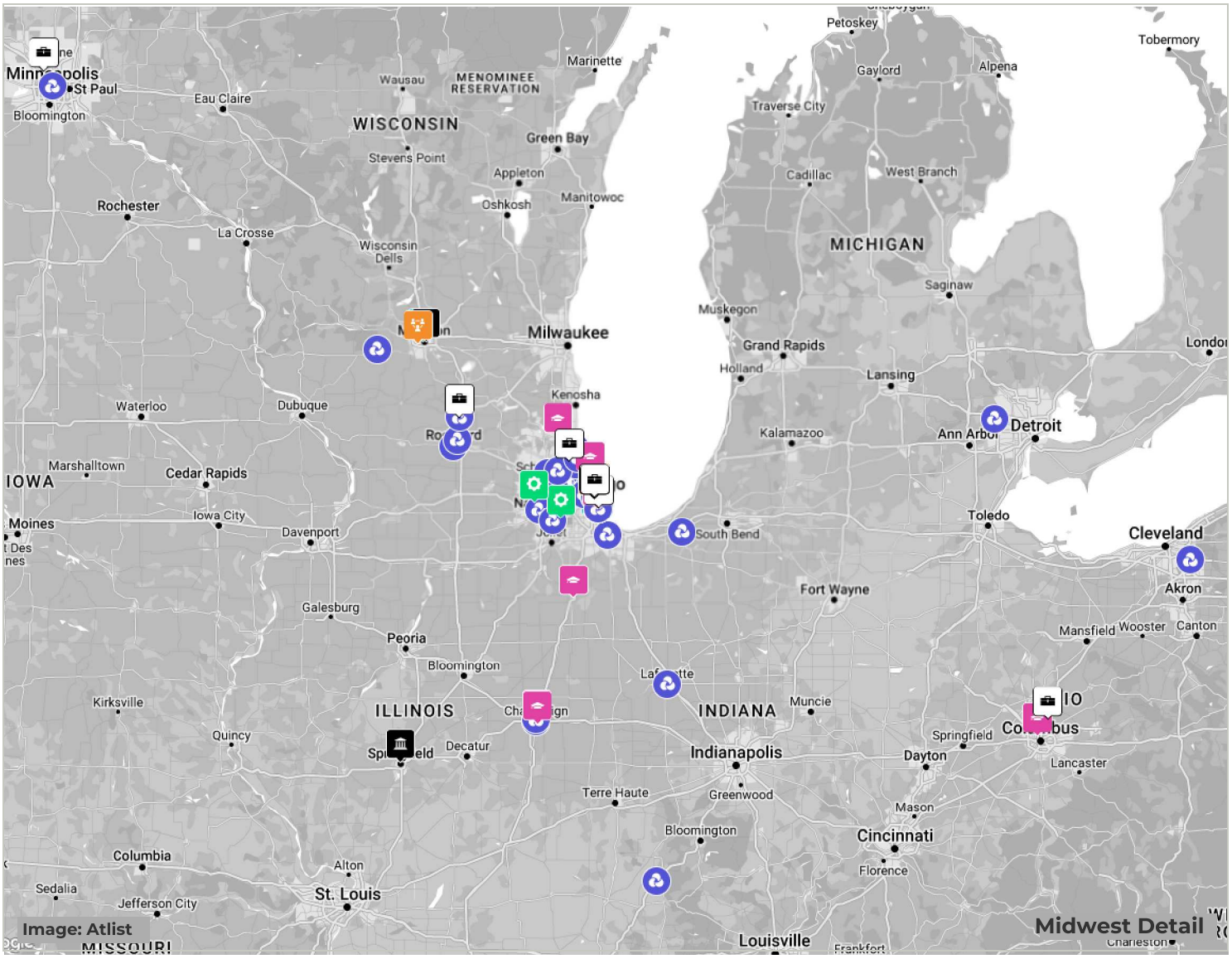
Chicago Quantum Exchange Partners

Non-Profit Partners

The Quantum Plains Ecosystem

The quantum ecosystem expands beyond the Chicago metropolitan area and into the greater Midwest; for example, the Chicago Quantum Exchange includes the University of Wisconsin-Madison as a member.

Other Midwestern participants in the quantum ecosystem include university partners, like The Ohio State University, as well as government partners, like the Illinois Department of Commerce and the State of Wisconsin's Department of Workforce Development.



Educational Partners and Institutions

Corporate Partners

Quantum Companies

National Labs

Government Partners

Chicago Quantum Exchange Partners

Non-Profit Partners

Chicago's Quantum Ecosystem

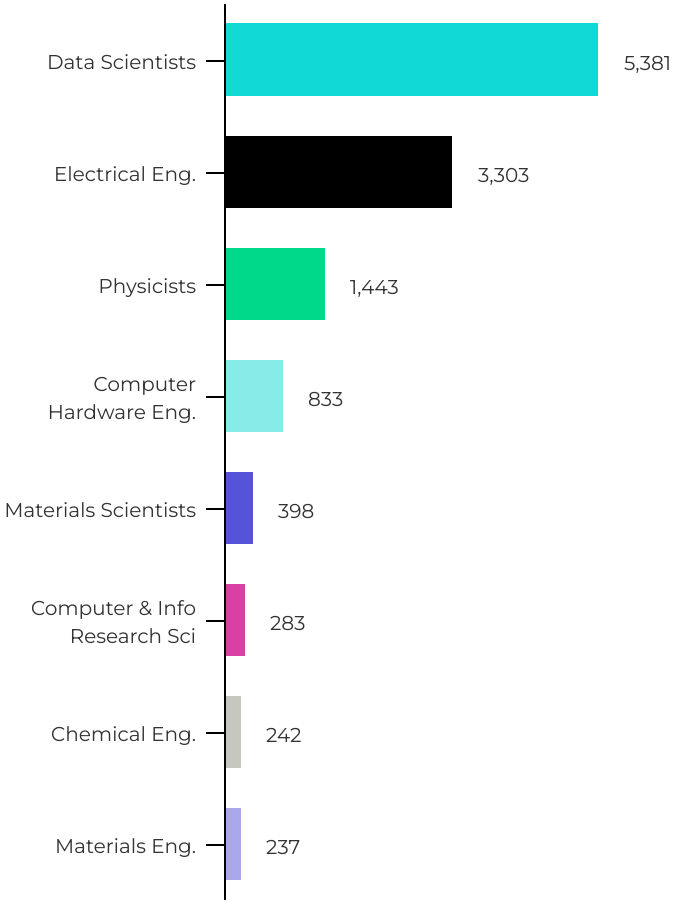
Chicagoland has nearly 12,000 workers available for the quantum industry distributed throughout the region.

Chicago has a sizable labor supply for increasing talent demands by quantum companies. As quantum technologies move beyond academia and into commercial applications, companies will likely need to tap into pools of existing talent that can adapt to or augment the workforce demands of quantum technology.

Chicagoland has nearly 12,000 workers in occupations related to quantum technology, including engineers, data scientists, and other scientist roles — projected to grow 7% by 2027. These workers are located throughout the Chicagoland region — with concentrations in Chicagoland's Northern and Western suburbs, as well as the city of Chicago — and offer companies looking to establish themselves in the region a geographic diversity of tech clusters to choose from.

Chicagoland offers highly specialized talent for quantum applications, including the **third most physicists and materials scientists** among all metro areas, and the **fifth most data scientists**.

Chicagoland's Quantum-Related Workforce 2022 Jobs by Occupation



Chicagoland's Quantum-Related Workforce 2022 Jobs by Zip Code

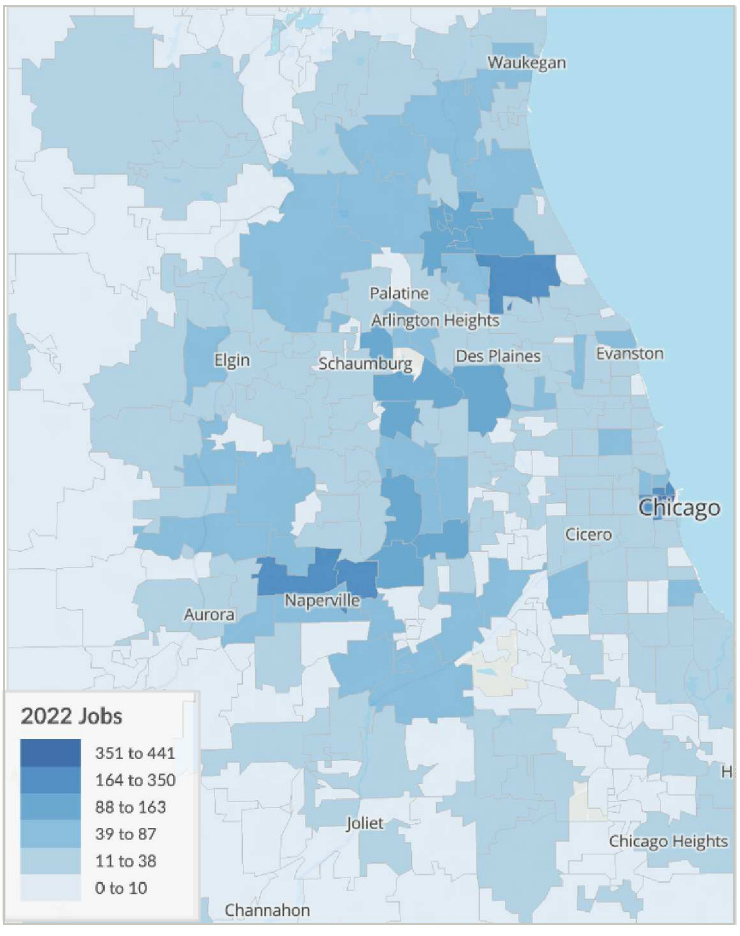


Image: Lightcast™

SPOTLIGHT

Chicago's Quantum Ecosystem

One of Chicago's first quantum companies, EeroQ is a developer and manufacturer of quantum computing hardware.

Dedicated to commercializing quantum processing, EeroQ's patented technology uses electron spin qubits (qubits being basic unit of quantum information), trapping and controlling individual electrons floating in a vacuum above superfluid helium, while the purity of the superfluid protects the intrinsic quantum properties of each electron. As the only commercial effort developing electrons-on-helium qubits, EeroQ has a unique position in the market.

Realizing the full potential of quantum computing — with applications that will revolutionize industries from pharmaceutical discovery to financial modeling — requires a utility-scale quantum computer, and EeroQ has put the scaling question at the forefront by developing scalable quantum chip architecture that can be manufactured in a traditional semiconductor foundry. The scaling-first strategy puts EeroQ's approach to quantum computing in a position to become a leapfrog technology. To date, other qubit approaches have demonstrated incremental scaling, some with more than 100 qubits in single processors, but have yet to develop a practical way to scale to several thousands on a single chip.

Harnessing the intrinsically high quality metrics of electrons-on-helium qubits with a scalable chip architecture, EeroQ plans to start offering cloud access to quantum computing users by 2025. EeroQ currently has a dozen employees, and raised $7.25 million of seed funding on August 23, 2022. It was the first firm to establish at the Terminal, a development on the West Side of Chicago.

Photo courtesy: EeroQ

Chicago's Competitive Advantages

Chicagoland offers a diverse and competitive industry ecosystem.

Chicago's diverse industry base creates a wealth of real-world challenges and applications for quantum companies to address. With industries spanning finance, healthcare, manufacturing, and more, quantum companies have ample opportunities to develop tailored solutions that can revolutionize various sectors and drive significant economic impact. **Chicago's market for IT-using firms is the nation's third largest, while the market for IT-producers is expected to grow by 14% by 2026.**

IT-using firms apply technologies to their oftentimes non-tech business models, while IT-producing firms develop and produce technology products or services as part of their business models. "High tech" firms are those that have the highest expenditures on research and development. A detailed list of the industry sub-sectors that make up these three broader categories can be found in the methodology section of this issue.

A broader view of Chicagoland's regional assets — including why the region is a competitive place to live and do business — can be found in "Chicagoland's Economic Assets," a report published with the Greater Chicagoland Economic Partnership.

IT-USING FIRMS

Rank among metro areas (2022)	**#3**
Projected Growth in GDP (2022-26)	**+9%**
GDP (Real, 2022)	**$126B**

EXAMPLE FIRMS:
- Computer Manuf.
- Telecommunications
- Computer Systems

IT-PRODUCING FIRMS

Rank among metro areas (2022)	**#10**
Projected Growth in GDP (2022-26)	**+14%**
GDP (Real, 2022)	**$52B**

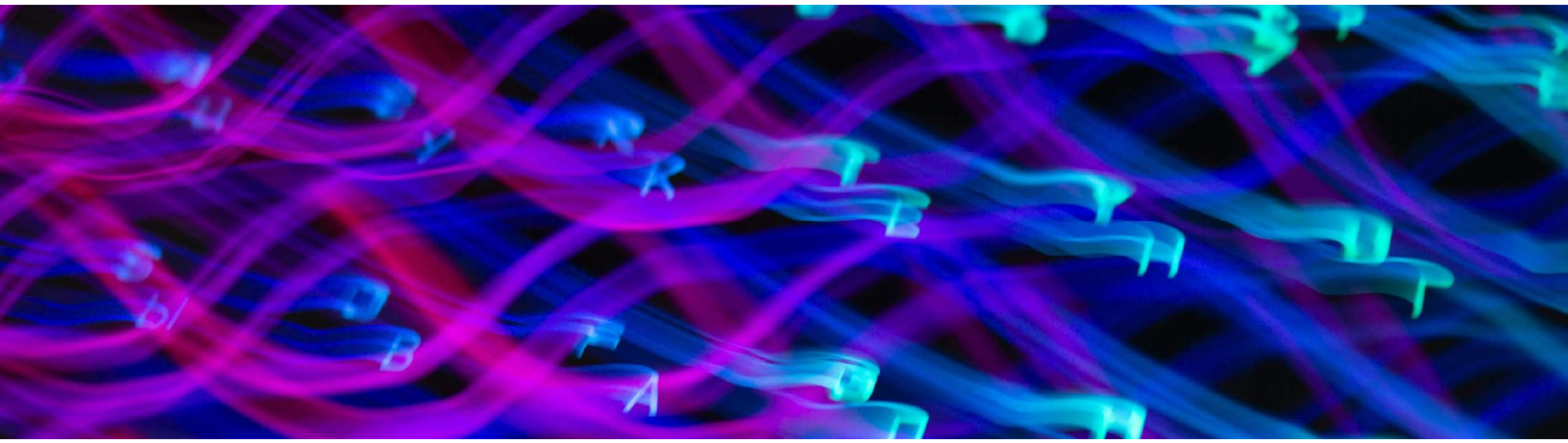
EXAMPLE FIRMS:
- Financial Investment
- Aerospace Manuf.
- Power Transmission

HIGH-TECH FIRMS

Rank among metro areas (2022)	**#9**
Projected Growth in GDP (2022-26)	**+15%**
GDP (Real, 2022)	**$72B**

EXAMPLE FIRMS:
- Pharmaceuticals
- Semiconductor Manuf.
- Satellite Telecomms.

*Gross Domestic Product (GDP) is the total value of goods and services produced in an economy. Real GDP adjusts for inflation.



Chicago's Competitive Advantages

IT-using, IT-producing, and High tech firms often acquire new technology as they innovate.

Collaboration enables quantum companies to validate their technologies in real-world settings, helping to refine their products and accelerate commercialization. Additionally, industry partners often possess the necessary resources, infrastructure, and market reach to scale up quantum technologies rapidly, accelerating their adoption and widespread implementation. As quantum computing evolves from a promising concept to a practical reality, collaboration with industry partners emerges as a powerful catalyst, propelling both quantum companies and traditional businesses into a future of unprecedented innovation and growth.

Quantum companies in the Chicago region will benefit from an ecosystem that includes firms that most often report acquiring technology, including intellectual property rights, as they innovate. **Nearly 50% of IT-using, IT-producing, and High Tech firms report that they must acquire new technology in order to innovate.**

By forging partnerships with established businesses, quantum companies gain access to valuable domain expertise, real-world use cases, and market insights that can guide the development of practical and impactful quantum solutions. Industry partners, in turn, benefit from the cutting-edge advancements in quantum computing, which can provide them with a competitive edge, improved efficiency, and new revenue streams.

50%

of technology-based firms acquired new tech in order to innovate

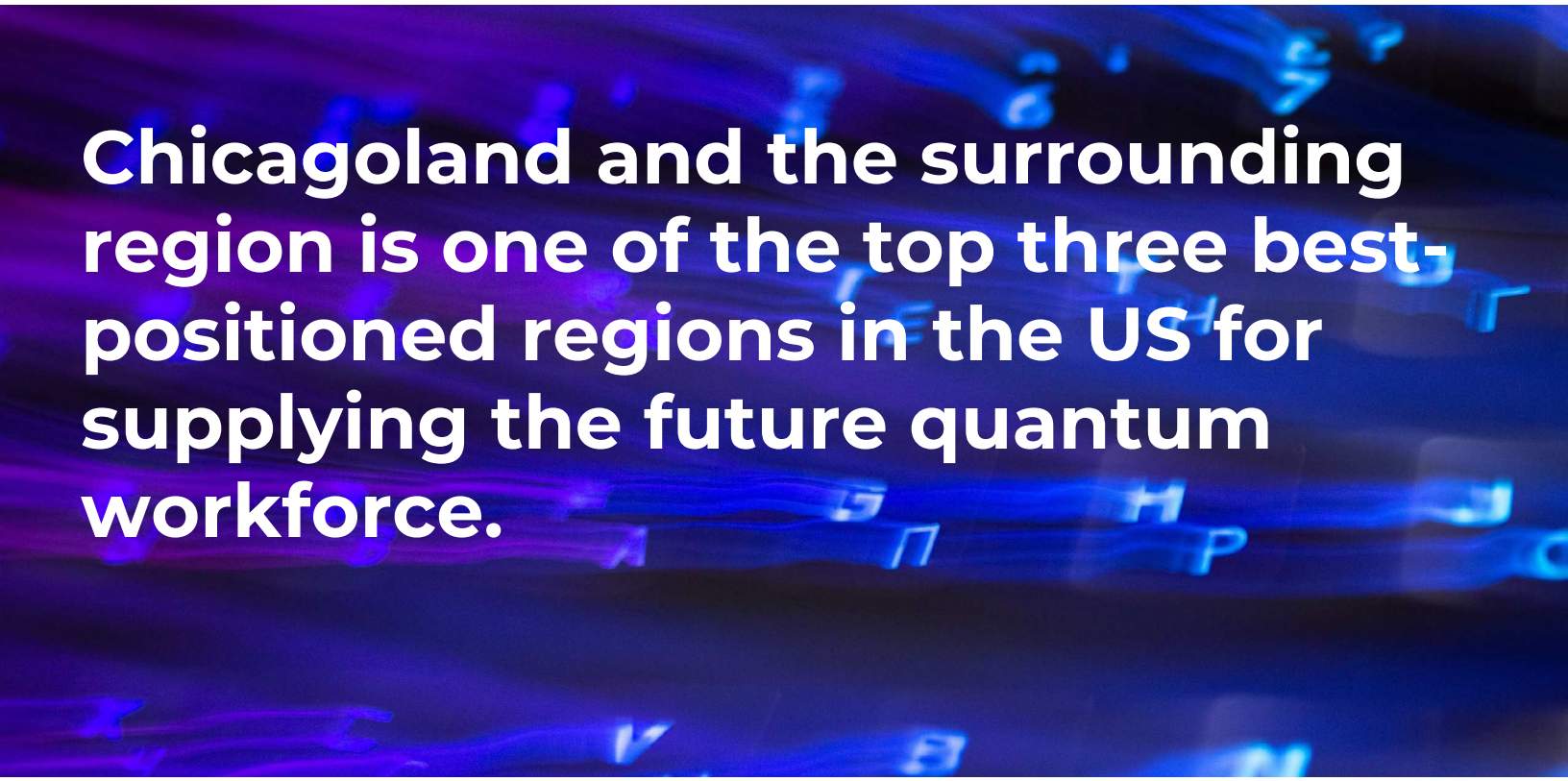
Quantum Talent Pipeline

Regional academic institutions like the University of Chicago, Northwestern University, the University of Illinois at Urbana-Champaign, and the University of Wisconsin-Madison, are global leaders in developing quantum experts.

Rapid advancements in quantum technology have accelerated the need to develop a quantum workforce; however, the industry faces a significant labor supply shortage. As a result, governments and organizations across the globe — including in the US — are formulating strategies to meet the labor demand requirements of of revolutionizing the quantum economy.

Domestically, one strategy is to expand student enrollment in degree programs, including Associate's, Bachelor's, Master's, Ph.D. programs, as well as non-degree professional training programs that provide quantum-related skills. Increased student participation would begin to resolve workforce gaps, helping Chicagoland achieve and maintain a competitive advantage in the quantum industry and related economic growth.

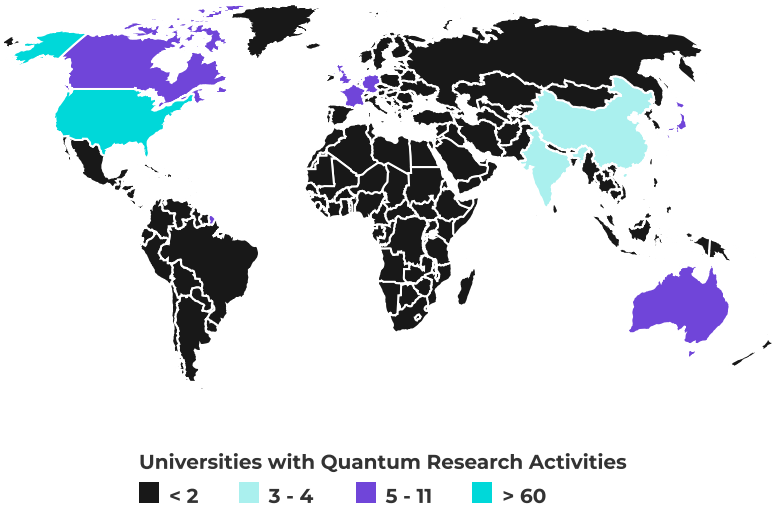
In response to the need for talent, quantum information science (QIS) and quantum computing (QC) have become high priority research areas in the United States, especially since Congress enacted the National Quantum Initiative (NQI) in 2018. University-based investigators have driven conceptual advances in fundamental physics that have furthered the frontiers in QIS and QC from the very beginning. **Many of the important breakthroughs in QIS have been accomplished at broader Chicagoland universities — including the University of Chicago, Northwestern University, the University of Illinois at Urbana-Champaign, and the University of Wisconsin-Madison — through partnerships with technology companies and national laboratories like Argonne National Laboratory and the Fermi National Accelerator Laboratory (Fermilab).**



US Quantum Research & Academic Programs

Illinois offers a sustainable and competitive environment for quantum-related research.

The World Business Chicago Research Center analyzed the global environment of research and academic programs to better understand Chicagoland's current, comparative position in preparing the necessary workforce and talent pipeline to take full advantage of the quantum revolution and its economic benefits. We analyzed this from both the perspective of research activities and academic programs and degrees.



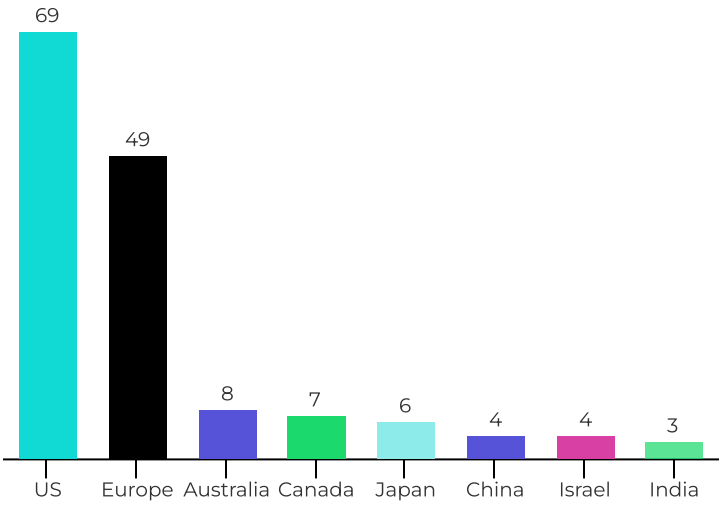
The US leads the world in the number of universities with research activity, with sixty-nine — 41.5% of the global total — universities participating in quantum research.

Illinois is a top state for quantum-related research, led by the Chicago Quantum Exchange (CQE). The CQE is based at the University of Chicago, and includes partners at Northwestern University and the INQUIRE Initiative, the University of Illinois at Urbana-Champaign, and Southern Illinois University's Quantum Computing Group. The partnership crosses state borders to include the University of Wisconsin-Madison and the Wisconsin Institute for Quantum Information.

American universities have been growing their research activities in QIS. These have typically been cross-disciplinary activities involving subsets of physics, chemistry, engineering, and computer science departments. Joint institutes, centers, and technology hubs have been successfully established at a number of institutions, including those at the University of Chicago, Northwestern University, Southern Illinois University, and the University of Wisconsin-Madison.

On the experimental side, some of these efforts have led to the formation of technology startup companies. The National Science Foundation (NSF) is supporting projects at universities in atomic, molecular, and optical physics (AMO), QC, QIS, and the quantum communication landscape, including the multi-institutional effort to build the world's first practical quantum computer.

Number of Universities with Quantum Research by Country



Chicago's Quantum Talent

Chicagoland's robust talent pipeline fuels the quantum computing revolution, and positions us to be a leader in the commercialization of quantum applications.

Understanding the talent needs of the quantum industry is critical to narrowing the workforce gap, and harnessing the transformational impact on the regional, national, and global economies. The most essential skill sets for working in the quantum industry include:

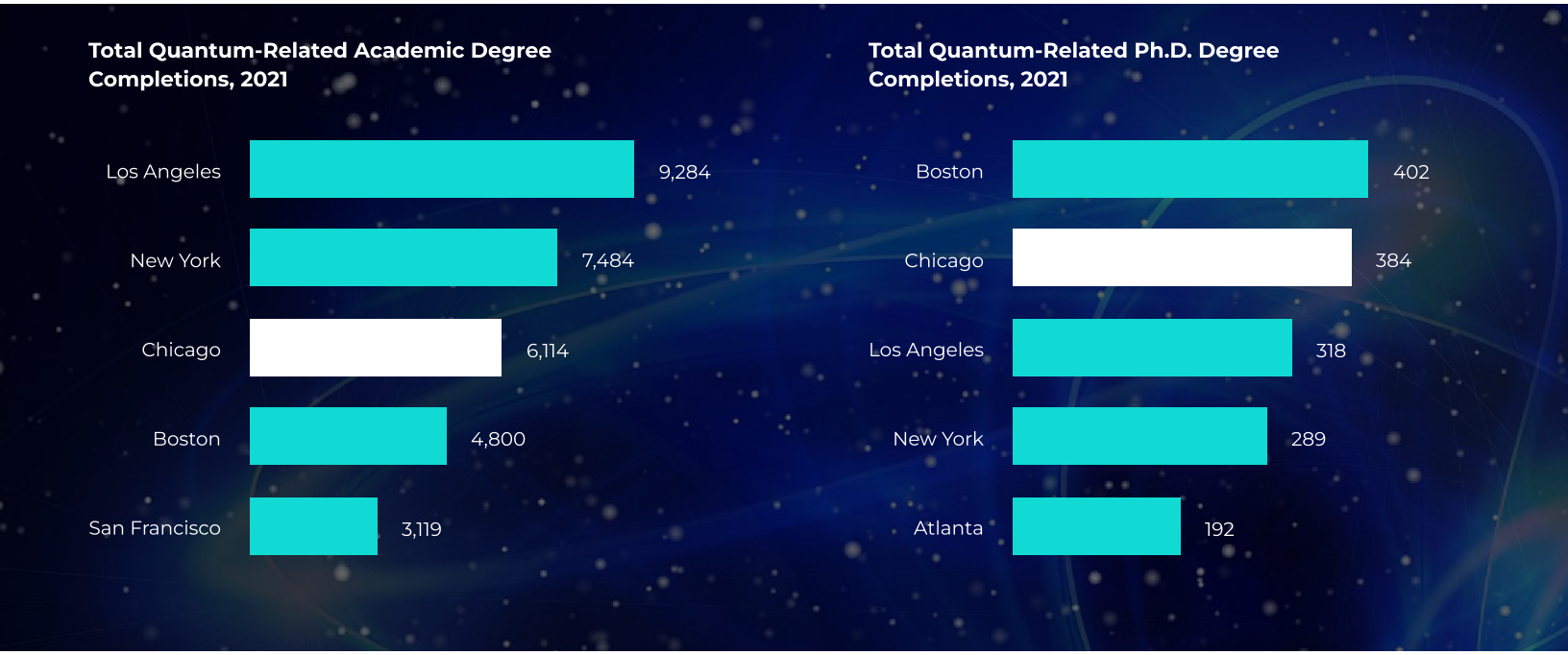
- a solid understanding of quantum physics fundamentals,
- deep quantum technology research experience and methods,
- detailed knowledge of the practical challenges in building and operating quantum technology, and
- foundational classical programming experience for quantum theory or experiment in Python, MATLAB, C++, or similar languages.

These skills can be found in academic degree programs such as **physics, electrical engineering, and computer science.**

Chicago Quantum Exchange partner universities rank second for number of quantum related Ph.D. graduates.

Chicagoland and the surrounding region are well positioned to supply the necessary workforce to meet the ongoing and future demand for the nascent and revolutionary quantum industry.

Institutions in the combined Chicago, Champaign-Urbana, and Madison metro areas have the **third most quantum-related academic degree completions in the nation** — including Associate's, Bachelor's, Master's and Ph.D degrees — with 6,114 in 2021, or roughly 5% of total degrees awarded nationally. Moreover, these institutions awarded the **second most Ph.D. degrees in the nation**: a total of 384 in 2021, or roughly 6% of total Ph.D degree completions.



Public Investment

Public investment fosters quantum R&D by driving innovation and nurturing a skilled workforce.

Quantum computing at the forefront of attracting substantial investments as the global race to harness the immense potential of quantum technologies is gaining momentum. The US is cementing its status as a world leader for quantum R&D; public funding is facilitating the growth and success of startups, driving research in quantum sensing and computing applications for major industrial sectors, and bridging the workforce talent gap through education initiatives. The future of quantum technology relies on public investment in both hardware manufacturing and high-level education and research.

Illinois serves as a role model for other states for its advanced academic programs, talented workforce, and well-developed laboratory infrastructure. These qualities make Illinois a top candidate for public investment in government initiatives, federal contracts, and grants. **Illinois leads the nation in total federal obligations, just ahead of California, while maintaining a large gap ahead the rest of the nation.**

In 2022, the US committed an additional $1.8 billion in funding quantum technologies. Quantum computing dominates investments among computing, sensing, and communications — the three main areas of quantum technologies — having raised $3 billion by the end of 2021. This aligns with its substantial potential market, estimated to surpass $90 billion annually by 2040.

Quantum sensing and communications gained $400 million and $700 million, respectively. The US government shows greater willingness than private investors to fund these areas, although more than half of US public funding remains dedicated to quantum computing, with the rest supporting quantum sensing and communications.

#1 **Federal Contract Funding for Quantum**

Illinois leads the US in federal contract funding with 27 contracts totaling $51,193,717.

#1 **Quantum Federal Obligation per Capita**

Illinois leads the US by a large margin with a federal obligation per capita of $4.03.

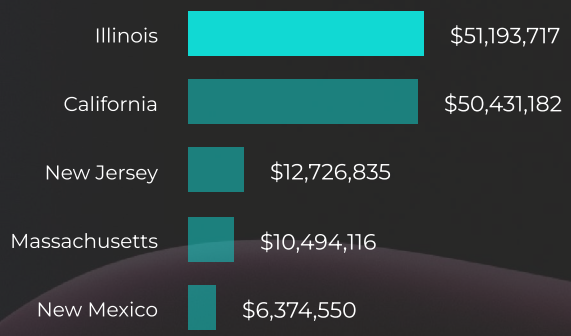
#3 **Number of Quantum Grants**

Illinois startups and universities have received 81 grants totaling an investment of $54,257,700

#3 **Number of Quantum SBIR & STTR awards**

Illinois ranks third in the US for SBIR/STTR programs with 73.

Top 5 States in Total Federal Obligations for Quantum Technology



Private Investment

Global investment has grown exponentially over the last ten years.

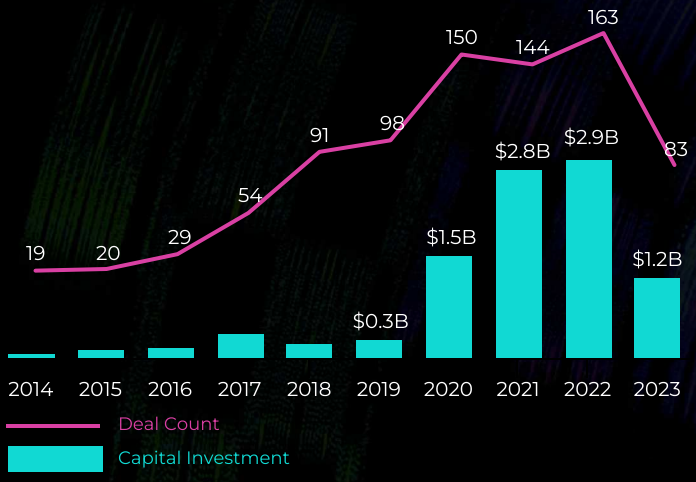
Private investment in quantum startups is fueling the commercialization of quantum technology, and the cumulation of efforts to move R&D beyond the lab and into the market.

GLOBAL & US INVESTMENT

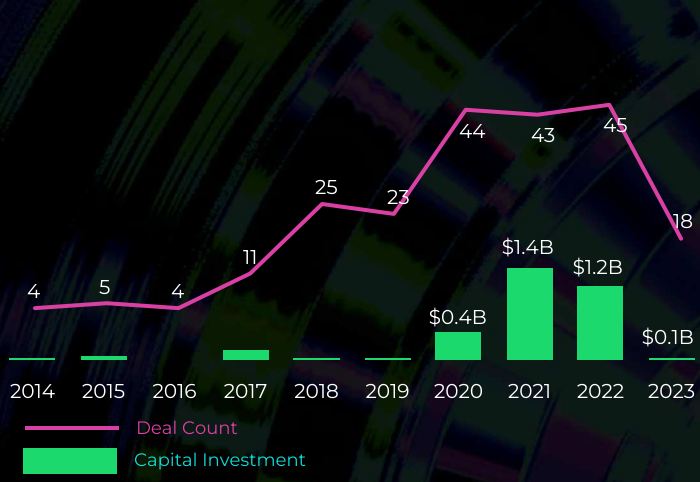
Beginning in 2020, private global quantum investment increased precipitously: $9.8B capital invested since 2020, compared to $1.4B between 2014 and 2019. Since 2014, countries with quantum startups receiving the largest investments include Canada, the United Kingdom, China, Japan, and Finland. Between 2022 and 2023, startups in Singapore, Denmark, and France also saw significant investment.

Investment in US quantum companies mirrors global investment: over $3B of capital invested since 2020, compared to just $405M between 2014 and 2019. Nearly half — 49% — of investors are located in New York, with another 40% in California.

Total Capital Investment in Quantum Companies Globally, 2014-2023



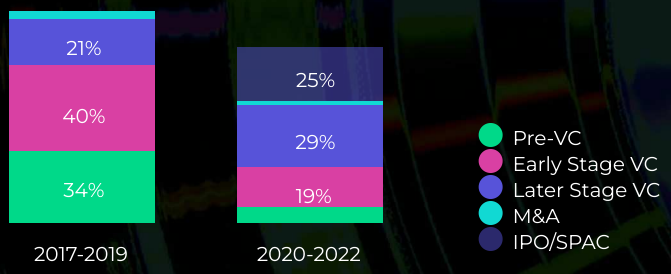
Total Capital Investment in Quantum Companies in the US, 2014-2023



GLOBAL DEAL TYPES

Global deals involving quantum companies have matured over the last seven years. Between 2017 and 2019, pre-venture capital — including government grants and seed funding — and early stage venture capital deals comprised of 74% of all capital investments, decreasing to 8% in the subsequent three years. Later stage venture capital deals increased from 21% to 29% of all capital raised in the same time period.

Percentage of Global Capital Investment by Deal Type, 2017-2022



Private Investment

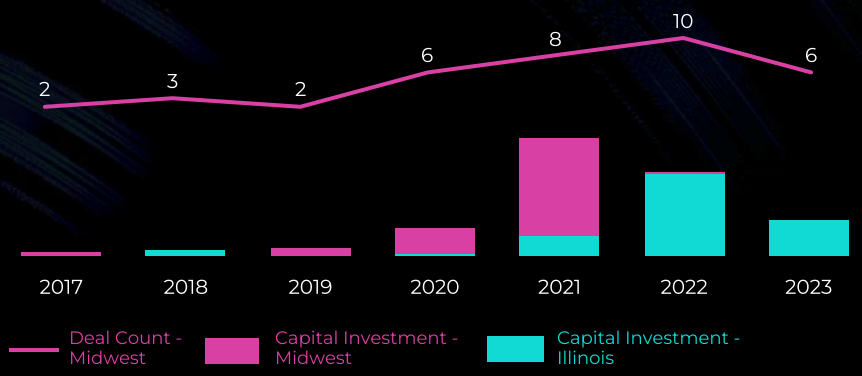
Illinois is the center of Midwestern quantum investment.

MIDWEST & ILLINOIS INVESTMENT
Since 2017, Midwestern quantum startups have raised $65.7 million through 37 deals; Illinois startups raised over half of that amount in $33.2 million through 27 deals.

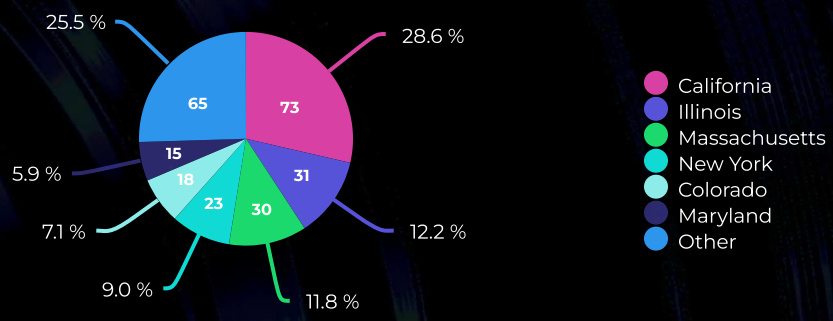
Illinois is a top state for deals made by quantum startups. Illinois ties with Massachusetts for the second highest number of deals recorded for all time, after California. However, Illinois ranks ninth out of twenty states with startups raising quantum capital, with $34.7 million for all time. The median post-deal valuation is also lower: $18 million versus $29.5 million nationwide.

However, Illinois has more seed round deals, and is poised for future growth in capital investment. More early stage activity is happening here: eight Illinois startups completed seed deals, second to California's thirteen companies and above five by Massachusetts companies.

Total Capital Investment in Quantum Companies in the Midwest and Illinois, 2017-2023



All Quantum Deals by State, 2012-2023



Quantum Startups that have Raised Over $1 Million in Capital Investment

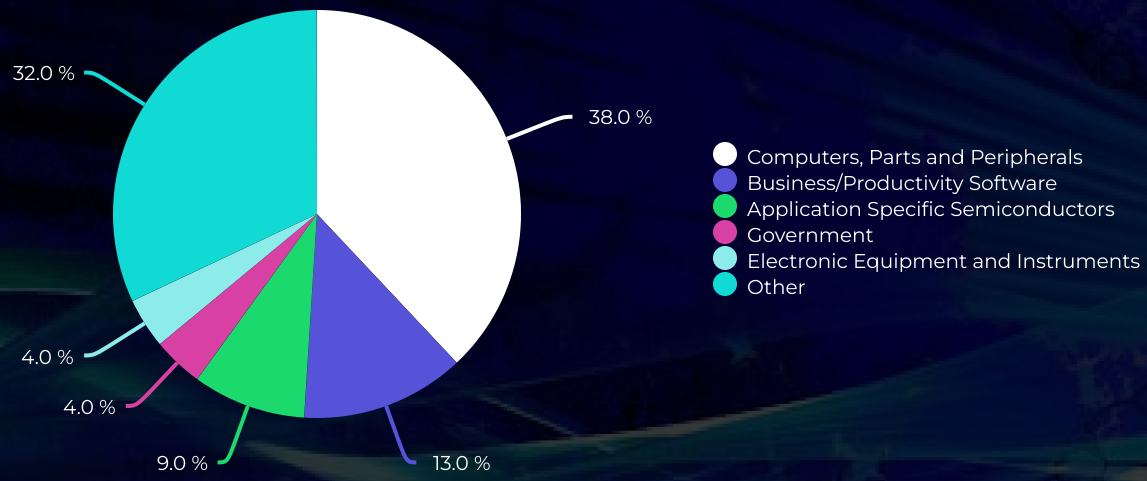
Company	Location	Industry	Most Recent Funding Stage
EeroQ	Chicago, Illinois	Semiconductors	Seed Round
FlexCompute	Madison, Wisconsin	Software	Later Stage VC
Mattiq	Skokie, Illinois	Other Materials	Grant
MemQ	Chicago, Illinois	Semiconductors	Seed Round
J2 Materials	Chicago, Illinois	Metals, Minerals & Mining	Buyout/LBO
qBraid	Chicago, Illinois	Software	Early Stage VC
Quantopticon	Chicago, Illinois	Software	Seed Round
Quantum Opus	Novi, Michigan	Electrical Equipment	Grant
Super.tech	Chicago, Illinois	Software	Merger/Acquisition
GLCT	Chicago, Illinois	Metals, Minerals & Mining	Early Stage VC

Private Investment

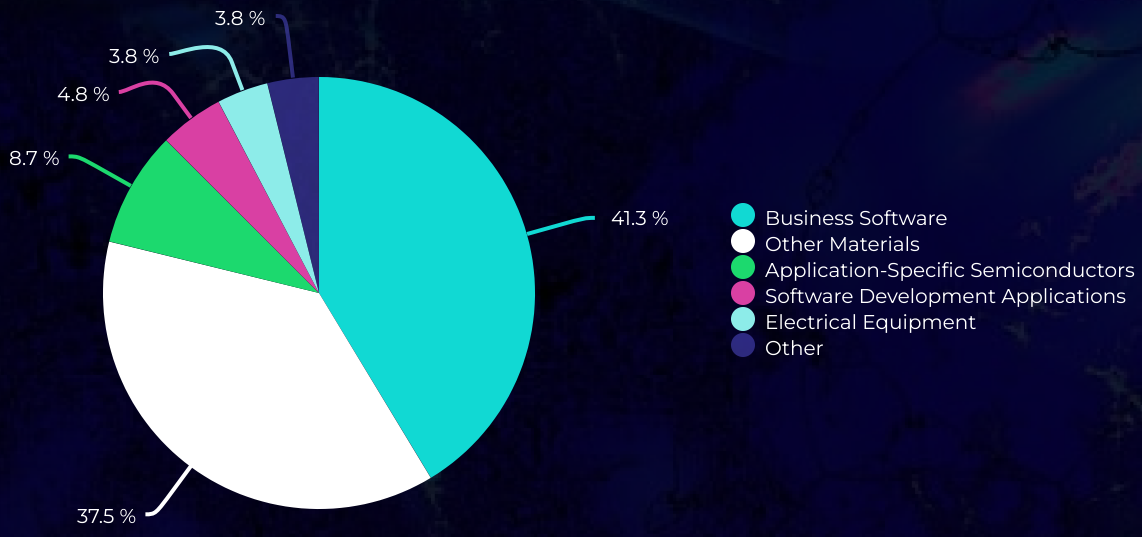
Quantum investment in Illinois looks different than global investment.

Capital investment figures for Illinois quantum-startups are reflective of the Midwest's unique quantum market: the flow of capital into Midwestern quantum startups is skewed more towards firms developing software-related technologies. This contrasts with global and US investment, which is more likely to be raised by firms developing computer hardware.

Top Industries for Global Quantum Investment



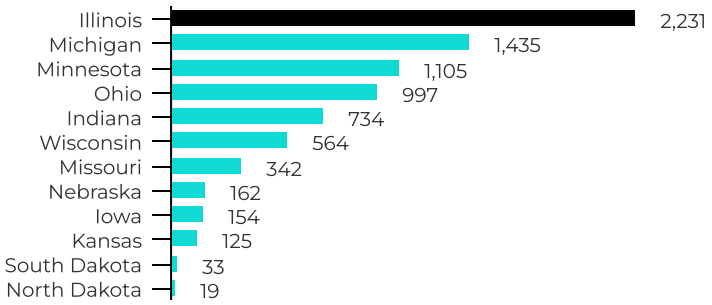
Top Industries for Midwestern Quantum Investment



Quantum Patents

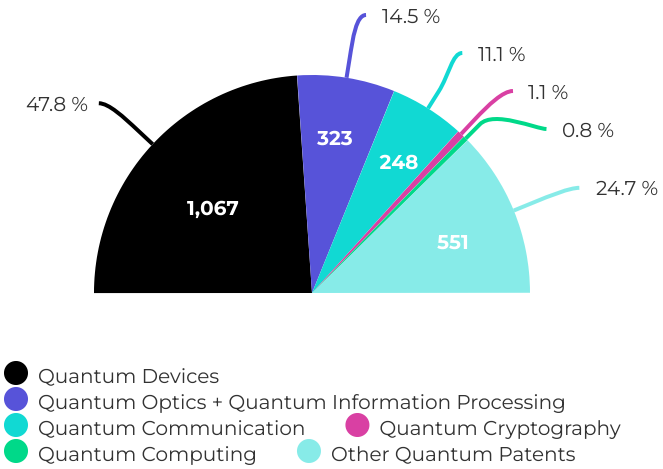
Illinois and Chicago both demonstrate a robust presence in the field of quantum patents.

Quantum Patents, Midwestern States



Illinois is a frontrunner in active quantum patents registered with the US Patent and Trademark Office, boasting 2,231 patents in the last decade. Illinois leads all Midwestern states, with 55% more than Michigan and 102% more than Minnesota. **Illinois' rich landscape of quantum patents showcases its success in cutting-edge R&D in quantum technology, and its position as a major Midwestern hub for quantum innovation.**

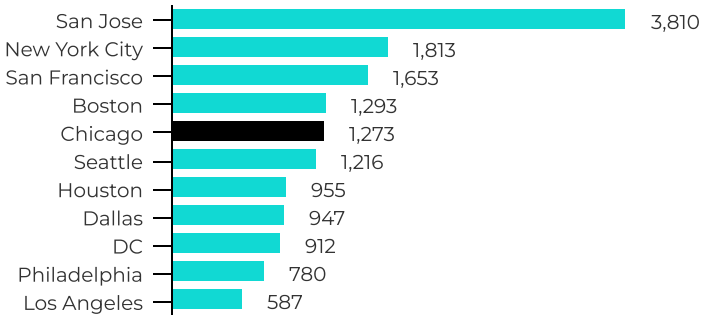
Distribution of Active Quantum Patents in Illinois



Illinois has a diverse, well-balanced distribution of quantum patents across sub-niches, especially compared to other high-performing states with significant quantum presences.

Notably, 47.8% of Illinois' quantum patents fall under quantum devices, while 14.5% are in quantum optics and quantum information processing. In contrast, California — the largest quantum patent producer — has over 70% of its patents in quantum devices and only 5% in quantum optics and quantum information processing.

Active Quantum Patents by Assignee City



Chicago is a leader in the quantum technology landscape, ranking fifth in the nation with 1,273 active quantum patents. Chicago demonstrates remarkable consistency and excellence across all quantum niches, ranking:

- **Third** among cities in quantum devices, quantum cryptography, and quantum communication
- **Fifth** among cities in quantum optics and quantum computing

Chicago's leadership in patents underscores its robust research institutions and visionary scientists, and role in driving technological breakthroughs with real-world impact and fostering cross-disciplinary collaborations for transformative advancements in quantum technology.

Active Patents by Sub-Niche

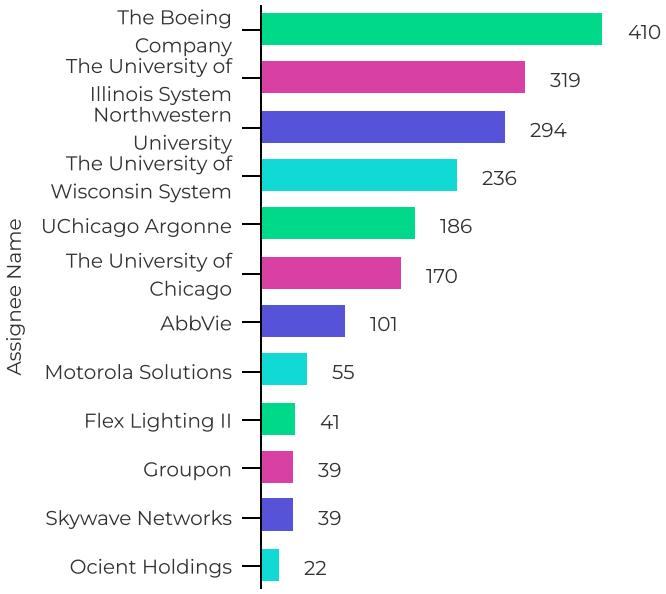
Quantum Patents

Illinois and the Midwest's quantum ecosystem is exemplified by the diversity of top patent holders and projected growth.

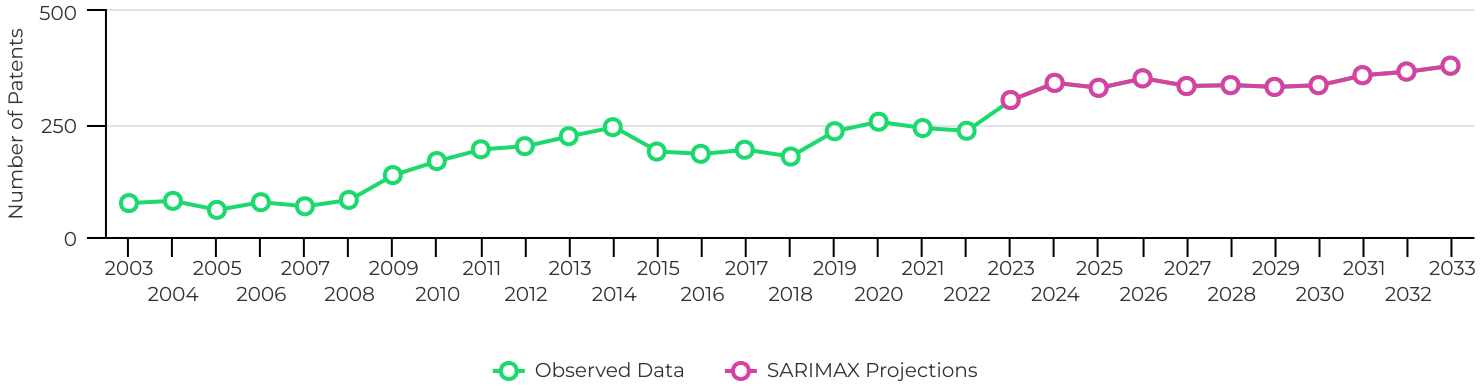
Together, Illinois and Wisconsin showcase an established quantum innovation ecosystem of academic and corporate partners. Companies like Boeing lead with 410 quantum-related active patents, while academic institutions — including the University of Illinois system, the University of Chicago, Northwestern University and the University of Wisconsin system — have 1,019 active patents. Argonne National Laboratory, a renowned federal-level research lab, demonstrates remarkable contributions with 186 active patents affiliated with quantum.

Chicagoland and the greater Midwestern region includes a diverse range of companies actively engaged in quantum research, including pharmaceutical giant AbbVie and telecommunications leader, Motorola. Top patent holders in the region also include emerging, non-traditional tech companies like Ocient Holdings and Flex Lighting II. Similarly, the Medical College of Wisconsin's 15 quantum patents signifies the impact of healthcare research in this cutting-edge field.

Top Active Quantum Patent Contributors in Illinois and Wisconsin by Number of Active Patents



Illinois Quantum Patent Growth by Year, with Projections



Illinois has exhibited remarkable performance in the growth of quantum patents, with the momentum expected to gradually speed up in the next ten years. From 75 patents in 2003, the number surged to 303 expected patents in 2023, with predictions based on the state's performance year-to-date. Illinois' quantum patents grew at a CAGR of 5% from 2009 to 2019. In comparison, the CAGR for the US patent market was 1.6% from 2009 to 2019. The Research Center's projection model indicates that Illinois' quantum patent landscape has further growth potential, with an expected 379 patents by 2033 and a CAGR of 2.3% from 2023 to 2033. This remarkable growth showcases Illinois' leading position in the quantum technology landscape, reaffirming its status as a key player in driving advancements at the intersection of finance, economics, machine learning, and complex data analytics.

Quantum Patents

Illinois' quantum landscape exhibits impressive performance in the usefulness of its patents and their potential to generate returns.

Illinois demonstrates a strong performance in generating high-quality patents capable of returning valuable investment, as evidenced by its top 10 most useful patents shown in the table below. The patents are primarily associated with prestigious research institutions and universities like the University of Chicago, the University of Illinois System, Northwestern University, and Argonne National Laboratory, and showcase the state's robust academic and research ecosystem. These patents cover diverse fields, ranging from advanced materials manipulation to quantum cryptography and electric field detection.

With an average usefulness index of approximately 86.63 out of the top 10, Illinois showcases its capability to produce disruptive innovations that have high relevancy to real-world quantum applications. The state's focus on research and development, as well as its ability to foster collaborations between the academia and the industry, have contributed to its success in generating valuable patents that push the boundaries of scientific knowledge and technological advancement.

Illinois' Top 10 Most Useful Quantum-Related Patents

Patent Number	Assignee	Patent Name	Usefulness (0-100)
US 8558333 B2	The University of Chicago	System And Method For Manipulating Domain Pinning And Reversal In Ferromagnetic Materials	93.29
US 8509274 B2	The Board of Trustees of the University of Illinois	Light Emitting And Lasing Semiconductor Methods And Devices	90.62
US 10673565 B2	Concio Holdings	Confirming Data Accuracy In A Distributed Control System	88.87
US 8582929 B2	Northwestern University	Ultra-sensitive Electric Field Detection Device	86.34
US 10475710 B1	UChicago Argonne	Method Of Characterizing The Anisotropic, Complex Dielectric Constant For Materials With Small Dimensions	85.98
US 11247914 B2	The University of Chicago	Colloidal Ternary Group III-V Nanocrystals Synthesized In Molten Salts	85.71
US 10333701 B2	The Board of Trustees of the University of Illinois	Reconfigurable Free-space Quantum Cryptography System	85.01
US 11152536 B2	The Board of Trustees of the University of Illinois	Photoresist Contact Patterning Of Quantum Dot Films	84.27
US 9134422 B2	The Boeing Company	Generation And Detection Of Frequency Entangled Photons	83.19
US 10541134 B2	The University of Chicago	Halometallate Ligand-capped Semiconductor Nanocrystals	83.03

Findings

1. **Chicago's diverse industry base creates a wealth of real-world challenges and applications for quantum companies to address.**

   Chicago is one of the top metro areas in the US for the industries — like high tech, IT-producing, and IT-using industries — that most often acquire new technology as part of their innovation strategies. Chicagoland's diverse business ecosystem creates a sizable customer base for the commercialization of quantum technologies. Moreover, Chicagoland also offers a significant workforce for quantum companies, with nearly 12,000 workers in quantum-adjacent roles, including the third most physicists and materials scientists in the nation.

2. **The Chicagoland region is one of the top three best-positioned regions in the US for supplying the future quantum workforce.**

   Within the US, the broader Chicagoland region (including Urbana-Champaign and Madison, Wisconsin) has the **third** highest number of universities engaged in quantum research activities and the **third** most universities with quantum-related degrees awarded. The greater Chicagoland region is a strong ecosystem for graduate quantum education, graduating the **second** most quantum-related doctoral students. This region also has the **second** most universities with actual Master's degree programs in quantum information science and technology.

3. **Global investment in quantum startups has increased dramatically since 2020; Illinois is a leader in US-based investments.**

   The private market is growing for quantum technologies, with global investments in quantum startups totaling $9.8 billion since 2020, up from $1.4 billion between 2014 and 2019. Illinois startups captured $47 million in investments since 2018; Illinois has the second most deals made by quantum startups after California. Investment in Illinois and Midwestern quantum startups is more likely to be captured by software-focused firms, compared to hardware-focused firms.

4. **Illinois has a diverse, well-balanced distribution of quantum patents across sub-niches, especially compared to other high-performing states with significant quantum presences.**

   Notably, 47.8% of Illinois' quantum patents fall under quantum devices, while 14.5% are in quantum optics and quantum information processing. In contrast, California — the largest quantum patent producer — has over 70% of its patents in quantum devices and only 5% in quantum optics and quantum information processing.

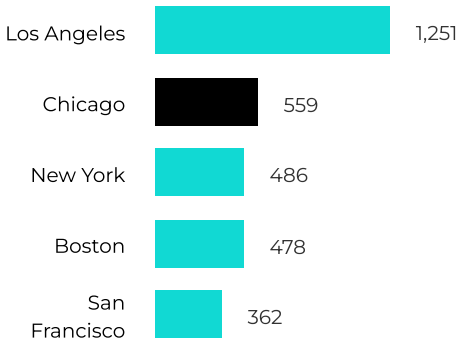
5. **Chicagoland is the anchor for the "Quantum Prairie."**

   Chicagoland is the nucleus of quantum activity in the Midwest, and anchors nearby top quantum ecosystems like Urbana-Champaign and Madison, Wisconsin. This is in large part because of the economic assets we have here, including two national laboratories, top research universities, connective transportation, and a resilient and affordable energy system.

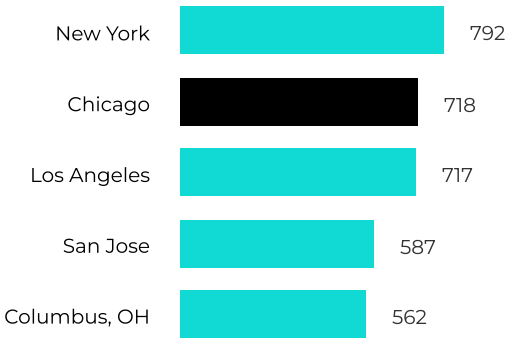
Appendix

Chicago and the broader region — including Urbana-Champaign and Madison, Wisconsin — produces the third most quantum-related degrees in the nation. Chicago and the region also offer considerable talent supply when looking at individual degree programs. Below are the top five metro areas for individual degree completions in 2021 — all degrees, including Associate's, Bachelor's, Master's, and Ph.D.

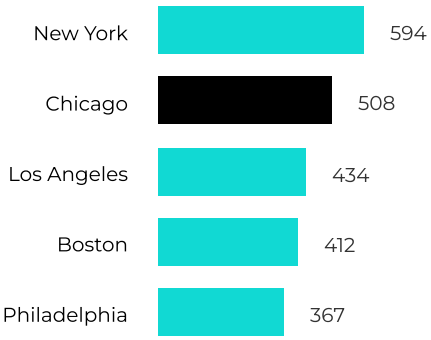
General Physics



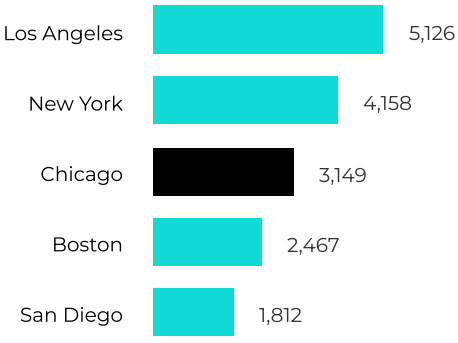
Computer Engineering



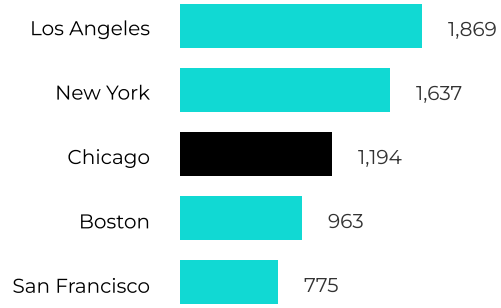
Chemical Engineering



Computer Science



Electrical and Electronics Engineering



Methodology

- **Industries included in IT-using, IT-producing, and high tech industry categories:** the numbers in the titles of the industry sub-sectors (e.g. 3251, Basic Chemical Manufacturing), correspond to NAICS codes (the North American Industry Classification System for business establishments by type of economic activity, as defined by the U.S. Census Bureau).

  IT-Using Industries:

  - 3251 Basic chemical manufacturing
  - 3259 Other chemical product and preparation manufacturing
  - 3252 Resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing
  - 3254 Pharmaceutical and medicine manufacturing
  - 3253 Pesticide, fertilizer, and other agricultural chemical manufacturing
  - 3336 Engine, turbine, and power transmission equipment manufacturing
  - 3353 Electrical equipment manufacturing
  - 3359 Other electrical equipment and component manufacturing
  - 3363 Motor vehicle parts manufacturing
  - 3346 Manufacturing reproducing magnetic and optical media
  - 3364 Aerospace product and parts manufacturing
  - 5417 Scientific research and development services
  - 3345 Navigational, measuring, electromedical, and control instruments manufacturing
  - 3333 Commercial and service industry machinery manufacturing
  - 3391 Medical equipment and supplies manufacturing
  - 2211 Electric power generation, transmission, and distribution
  - 5511 Management of companies and enterprises
  - 2212 Natural gas distribution
  - 4236 Electrical and electronic goods merchant wholesalers
  - 4251 Wholesale electronic markets, agents, and brokers
  - 4541 Electronic shopping and mail-order houses
  - 5211 Monetary authorities - central bank
  - 5222 Nondepository credit intermediation
  - 5223 Activities related to credit intermediation
  - 5239 Other financial investment activities
  - 5241 Insurance carriers
  - 5418 Advertising and related services
  - 5121 Motion picture and video industries
  - 5413 Architectural, engineering, and related services
  - 5419 Other professional, scientific, and technical consulting services
  - 5416 Management, scientific, and technical consulting services
  - 5611 Office administrative services
  - 6215 Medical diagnostic laboratories

  IT-Producing Industries:

  - 3341 Computer and peripheral equipment manufacturing
  - 3343 Audio and video equipment manufacturing
  - 3346 Manufacturing and reproducing magnetic and optical media
  - 3344 Semiconductor and other electronic component manufacturing
  - 3363 Motor vehicle parts manufacturing
  - 5173 Wired and wireless telecommunications carriers
  - 5179 Other telecommunications
  - 4234 Professional and commercial equipment and supplies merchant wholesalers
  - 4431 Electronics and appliance stores
  - 5415 Computer systems designs and related services
  - 5182 Data processing, hosting, and related services
  - 5112 Software publishers

  High-tech Industries:

  - 3254 Pharmaceutical and medicine manufacturing
  - 3341 Computer and peripheral equipment manufacturing
  - 3342 Communications equipment manufacturing

Methodology

(continued) High-tech Industries:

- 3344 Semiconductor and other electronic component manufacturing
- 3345 Navigational, measuring, electromedical, and control instruments manufacturing
- 3391 Medical equipment and supplies manufacturing
- 5112 Software publishers
- 5173 Wired and wireless telecommunications carriers
- 5174 Satellite telecommunications
- 5179 Other telecommunications
- 5191 Other telecommunications services
- 5182 Data processing, hosting, and related services
- 5415 Computer systems design and related services
- 5417 Scientific research and development services
- 5419 Other professional, scientific, and technical services
- 6215 Medical and diagnostic laboratories

- **Quantum patents, defined by CPC codes:** quantum devices (CPC: H01L), quantum optics and quantum information processing (CPC: B82Y), quantum computing (CPC: G06N10/00), patents, and quantum communication (CPC: H04B10).
- **The projection model for Illinois' quantum patent growth** uses the SARIMAX (Seasonal Auto-Regressive Integrated Moving Average with eXogenous factors) model fitted with the optimal AIC (Akaike Information Criterion). This model takes into account any seasonality and exogenous variables in the form of external data in the forecast. Some examples of exogenous variables included are the state of the economy, government policies and funding, risk-free rate (we use the 10-year Treasury rate as the closest proxy), presence of research institutions, etc.
- **The patent valuation model** is developed to predict potential usefulness of patents based on existing patent information and content, such as patent classification, number of applications, claims, cited patents, cited non-patent publications, number of authors, and number of similar documents. The model returns a useful index of a scale from 0 to 100, which assesses both how relevant the patent is to quantum and how likely the patent will be able to return valuable investment until its expiration. Quantum-related patents approved by USPTO from 2010 to 2023 were extracted from Google Patents database. A classifier model and a Word2Vec model were trained on all quantum-related patents from 2010 to 2018 to learn keywords and features related to quantum. The final model was then fitted through a logistic regression and a random forest model to assess the usefulness of all active quantum patents in the state of Illinois, with a test set accuracy of 0.991 and an average F-score of 0.996.
- **Quantum talent**: based on the following 15 National Center for Education Statistic's Classification of Instructional Programs (CIP) codes for quantum-related academic programs: Physical Chemistry (40.0506), Chemical Physics (40.0508), General Physics (40.0801), Atomic/Molecular Physics (40.0802), Elementary Particle Physics (40.0804), Nuclear Physics (40.0806), Optics/Optical Sciences (40.0807), Theoretical and Mathematical Physics (40.0810), Physics and Astronomy (40.1101), Computer Science (11.0701), Chemical Engineering (14.0701), Electrical and Electronics Engineering (14.1001), Materials Science (40.1001), General Computer Engineering (14.0901), and General Data Science (30.7001).
- **Quantum workforce:** based on the following 8 US Bureau of Labor Statistic's Standard Occupational Classification (SOC) codes: Chemical Engineers (17-2041), Materials Engineers (17-2131), Data Scientists (15-2051), Electrical Engineers (17-2071), Physicists (19-2012), Materials Scientists (19-2032), Computer and Information Research Scientists (15-1221), Computer Hardware Engineers (17-2061).
- **Pitchbook and private investment**: based the search Industry > Emerging Spaces > Information Technology > Quantum Computing.

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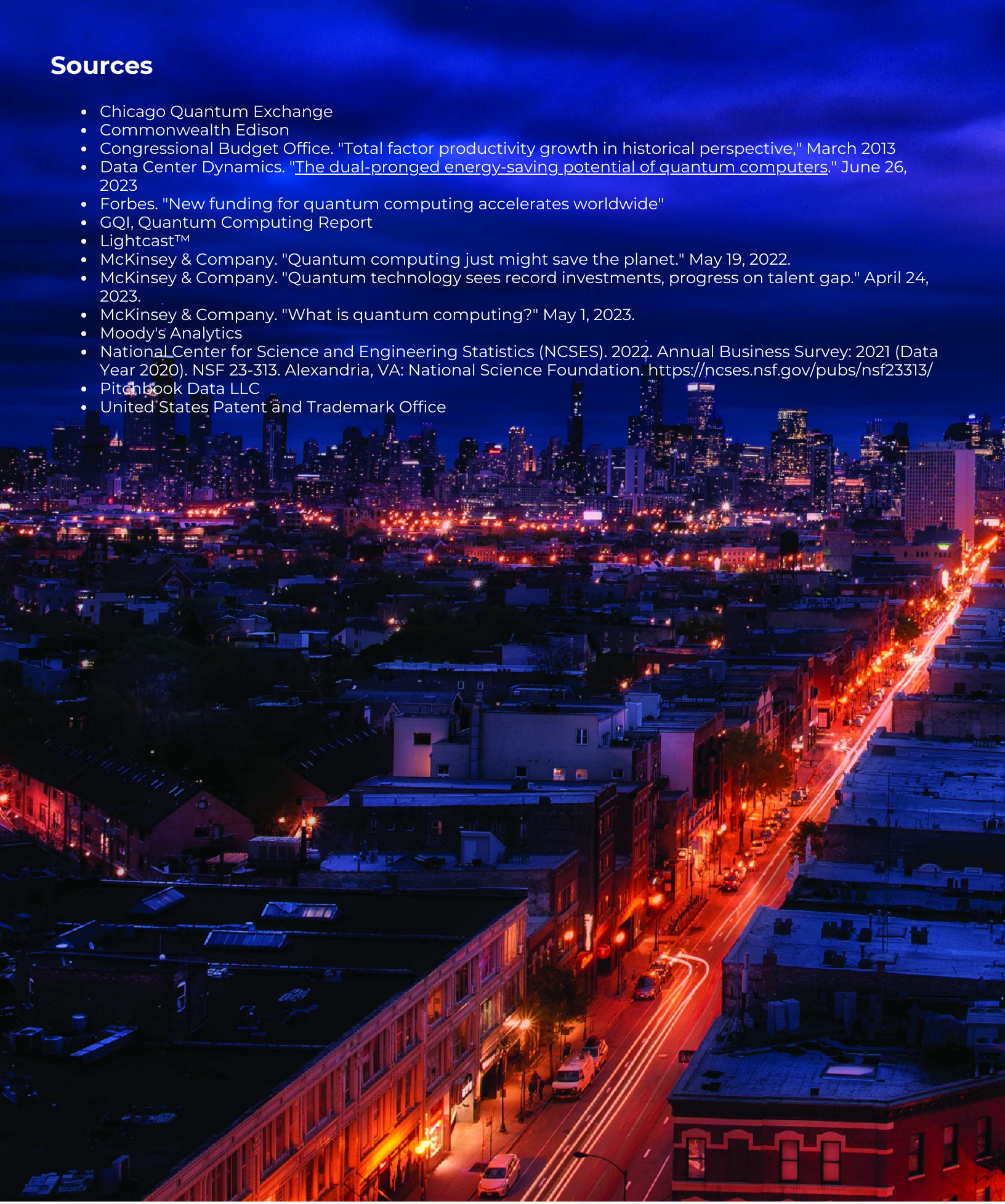

Chicago Business Bulletin

About

World Business Chicago is Chicago's public-private economic development agency. Our mission is to drive inclusive economic growth and job creation, support businesses, and promote Chicago as a leading global city. Our vision is to ensure that all Chicagoans prosper.

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