Deloitte.

# The Greater Toronto Area's Quantum Science and Technology Ecosystem

## Executive Summary

**January 2023**

Source: University of Toronto, 2022

# Disclaimer

This draft executive summary has been provided by Deloitte LLP (“Deloitte”) for the purpose of characterizing the University of Toronto’s (“U of T”), (“University”) role in the quantum sciences and technologies ecosystem within the Greater Toronto Area (“GTA”). This study, nor this executive summary does not represent an analysis of recommendations for the University to position itself in the ecosystem and does not represent a comparison of the potential economic impacts of U of T’s activities to the Canadian/Ontario or GTA’s economy. In particular, this draft study does not examine the potential costs of pursuing the capital investments or operational activities, including the opportunity costs for U of T, or other stakeholders. For detailed analysis please review the report which has been submitted under separate cover.

Deloitte does not assume any responsibility or liability for losses incurred by any party as a result of the circulation, publication, reproduction or use of this initial analysis contrary to its intended purpose. This analysis has been made only for the purpose stated and shall not be used for any other purpose. No party other than U of T is entitled to rely on this analysis for any purpose whatsoever and Deloitte accepts no responsibility, liability, or duty of care to any party other than U of T.

The study is based on analysis that was concluded as of Aug 31, 2022, and we disclaim any undertaking or obligation to advise any person of any change in any fact or matter affecting this analysis, which may come or be brought to our attention after the date hereof. It can be noted that selected analysis has been prepared by the University and included in this study that has not been independently verified by Deloitte. This analysis is clearly marked in this study and sourced to U of T as required. In preparing this report, we have relied on data and information provided to us by U of T and other relevant stakeholders consulted as a part of this analysis. The analysis presented in this report is subject to the general qualification that the information and data provided to us are accurate and reliable and are also subject to the accuracy of the various assumptions described within the report. We reserve the right to amend any part of our report, or the conclusions expressed herein, in the event new or amended information is provided to us after the date of this report.

Without limiting the foregoing, if there is any material change in any fact or matter affecting the analyses after the date hereof, we reserve the right to change or modify the analysis but are under no obligation to do so. Observations are made based on economic, industrial, competitive and general business conditions prevailing as at the date hereof. In the analyses, we may have made assumptions with respect to the quantum industry performance, general business, and economic conditions and other matters, many of which are beyond our control, including government and industry regulation and trends.

The full extent of the ongoing COVID-19 pandemic’s impact on the economic outlook remains uncertain. It is, therefore, important for readers to consider that the analysis of the quantum ecosystem is based on third-party data (e.g., economic and industry data) available up to August 2022 and does not include any consideration of the likely economic impact of either COVID events or the related fiscal stimulus measures on the industry herein.

No opinion, counsel, or interpretation is intended in matters that require legal or other appropriate professional advice. It is assumed that such opinion, counsel, or interpretations have been, or will be, obtained from the appropriate professional sources. To the extent that there are legal issues relating to compliance with applicable laws, regulations, and policies, we assume no responsibility, therefore.

We believe that our analyses must be considered as a whole and that selecting portions of the analyses, or the factors considered by them, without considering all factors and analyses together, could create a misleading view of the issues related to the draft report. Amendment of any of the assumptions identified throughout this draft report could have a material impact on our analysis contained herein. Should any of the major assumptions not be accurate or should any of the information provided to us not be factual or correct, our analyses, as expressed in this draft report, could be significantly different.

# The Global Quantum Opportunity

**Quantum technologies can change the way we live – and universities have a leadership role to play in driving this transition.**

A study commissioned by the National Research Council of Canada in 2020 estimates that the total economic impact of quantum in Canada (both direct and indirect effects) will be $533 million, bringing 1,100 direct and indirect jobs by 2025.

By 2045, this industry is expected to reach almost $140 billion and generate over 209,000 jobs.

The Greater Toronto Area (GTA) is at the forefront of quantum sciences and technologies and leads in terms of total population and total venture capital raised and is well positioned to become a leading quantum hub.

Sources: A National Quantum Strategy for Canada, 2018

# Quantum Sciences Can Help Solve Society's Intractable Problems

## Examples of quantum sciences in action

### Financial Services

Quantum computing promises better algorithms optimizing everything from financial modelling to trading strategies and asset valuations, delivering better results to investors.

### Natural Resources

Quantum sensing promises more accurate monitoring of oil and gas reserves, mineral deposits and better management of energy resources, ensuring a more efficient use of natural resources.

### Health and Life Sciences

Quantum imaging promises more accurate scan of the human body, while quantum computing promises novel drug development capabilities, that will save lives.

### Technology, Media and Communication

Quantum communication and cryptography promises more secure, less energy intensive communications, new semiconductor materials and network optimization, enabling better communication.

Sources: A National Quantum Strategy for Canada, 2018, 2022.. Quantum Computing is Coming. What Can It Do ?, Harvard Business Review, 2022

# Recent Announcements - The National Quantum Strategy

- Given global investment levels, Canada encounters significant competition for quantum science and technology strength.
- In the 2021 budget, the Government of Canada earmarked $360 million over 7 years to launch the NQS, building on an earlier investment of $1 billion.

**The key pillars of the NQS, released in January 2023, are**

- Amplify Canada's significant strength in quantum research.
- Help develop, attract and retain quantum talent in Canada.
- Commercialize quantum research to further the adoption of made-in-Canada quantum technologies.

**During consultations leading up to the release of the strength in January 2023, stakeholders made recommendations on how Canada can advance its leadership in this sector**

- Among the participants of the roundtables was a consensus around the theme of urgency and action. Although Canada currently leads many areas of inquiry, it needs to continue to pioneer research and accelerate its application to keep its competitive advantage and retain its talent base.
- There is competition for quantum talent among sectors and for top students and researchers.
- Current levels of public investment in the NQS are not sufficient to achieve the Canadian quantum community's goals compared to global investment by peers.
- Awareness is necessary both from an end-user perspective and through a branding strategy for the sector.
- Collaboration is important, including international and with industry , because of Canada's market size.

**Challenge**

Although Canada's efforts are laudable, the international competition is fierce, and the earmarked budget is only a fraction of some of Canada's prime competitors in the industry. As such, Canada needs to focus on international co-operation and fundamental research to achieve its goal as it cannot outspend the competition.

*Dollar amounts are in CAD unless specified otherwise.
Sources: Industry Canada, National Quantum Strategy : What We Heard Report, 2022

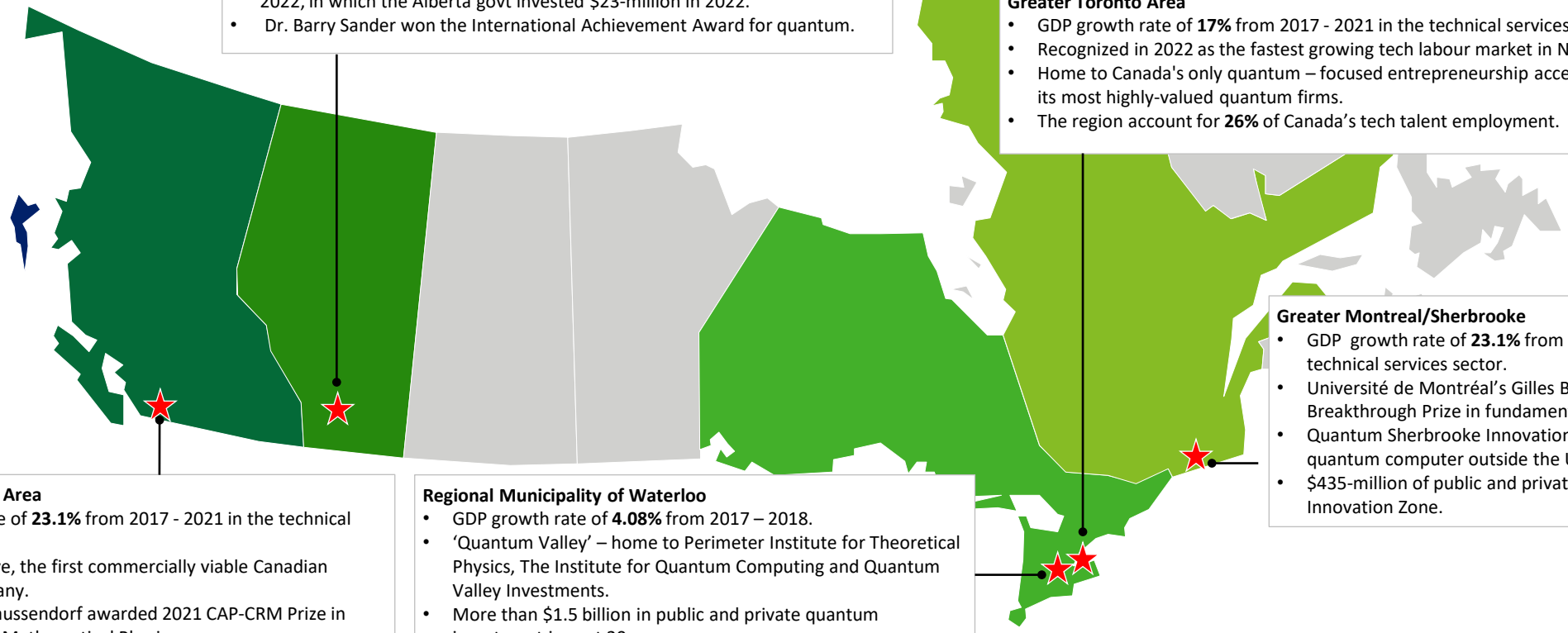
# The Global Race for Quantum Science

**Canada's recent NQS investment is an important step in the right direction, but is modest compared to peers and will require coordinated action between researchers, universities, firms and the government to achieve its goals.**

| New Investments | | | Key Areas of Focus | Total investment |
|---|---|---|---|---|
| Recent investment **$15.3 B** | The investment is part of China's "Made in China 2025" plan. | Includes the Made in China 2025 plan plus the investment made from 2011 to 2018 and includes sums spent to develop and launch their communication network. | **Quantum Communications** | **$25.3 B** *($18/capita)* **CHINA** |
| Recent investment **$2.4 B** | As part of the 2021 budget, Germany will invest €2 billion. | Includes the recent investment plus the 2018: From Basic Research to Market plan, which earmarked another €2 billion to support quantum technology go to market strategy. | **Quantum Computing** | **$4.8 B ($57/capita)** **GERMANY** |
| Initial investment **$1.2 B** | As part of the 2018 National Quantum Initiative Act. | Revised figure in the 2022 Federal Budget. Split between 1.2 base financing and $1.6 billion NQI financing over the last 4 years (2019-2022). **Investments through the CHIPS and Science Act are not captured in this amount.** | **Quantum Information Science** | **$2.8 B ($8.5/capita)** **UNITED STATES** |
| NQS investment **$360 M** | Over the next 7 years (2021-2028) | Investment made over the last 12 years. Total investment includes the future National Quantum Strategy funds. | **Fundamental Quantum Research** | **$1.2 B** ***($31/capita)*** **CANADA** |

Sources: Quantum.gov, Strategy, 2022; CIFAR, A Quantum Revolution : Report on global policies for quantum technology, 2021; Quantum Computing Report, How much money has China already invested into quantum technology, 2022. .
Note that the figures presented herein represent public investment levels only. Private investment is not captured.

# Spotlight: Canada's quantum hubs



**Greater Calgary Area**
- GDP growth rate of -**1.1%** from 2017 - 2021 in the technical services sector.
- Home to *Quantum City* – a new quantum science tech hub announced in 2022, in which the Alberta govt invested $23-million in 2022.
- Dr. Barry Sander won the International Achievement Award for quantum.

**Greater Toronto Area**
- GDP growth rate of **17%** from 2017 - 2021 in the technical services sector.
- Recognized in 2022 as the fastest growing tech labour market in North America.
- Home to Canada's only quantum – focused entrepreneurship accelerator and several of its most highly-valued quantum firms.
- The region account for **26%** of Canada's tech talent employment.

**Greater Montreal/Sherbrooke**
- GDP growth rate of **23.1%** from 2017 - 2021 in the Quebec technical services sector.
- Université de Montréal's Gilles Brassard, recipient of the Breakthrough Prize in fundamental physics.
- Quantum Sherbrooke Innovation Zone; Home to IBMs 4th quantum computer outside the USA.
- $435-million of public and private investment allocated to Innovation Zone.

**Greater Vancouver Area**
- GDP growth rate of **23.1%** from 2017 - 2021 in the technical services sector.
- Home to D-Wave, the first commercially viable Canadian quantum company.
- UBC's Robert Raussendorf awarded 2021 CAP-CRM Prize in Theoretical and Mathematical Physics.

**Regional Municipality of Waterloo**
- GDP growth rate of **4.08%** from 2017 – 2018.
- 'Quantum Valley' – home to Perimeter Institute for Theoretical Physics, The Institute for Quantum Computing and Quantum Valley Investments.
- More than $1.5 billion in public and private quantum investment in past 20 years.

Sources: Statistics Canada, 2022, Gross domestic product (GDP) at basic prices, by census metropolitan area (CMA) (x 1,000,000); Statistics Canada, 2022, Gross domestic product (GDP) at basic prices, by industry, provinces and territories, growth rates (x 1,000,000); CBC, 2022, Montreal's Brassard wins Canada's top science medal; CTV, 2022, Quebec unveils two 'innovation zones' east of Montreal, including Canada's first quantum computer; CTV, 2022, Alberta announces $23M to create new quantum hub at University of Calgary; UofC, 2022, UCalgary community members honored at prestigious Calgary Awards; UBC, 2021, Robert Raussendorf wins CAP-CRM Prize in Theoretical and Mathematical Physics; Science Business, 2021, Canada steps up investments in quantum technologies; EDC, A complete theory-to-commercialization quantum ecosystem; The Quantum Insider, 2021, 12 Quantum Technology Startups Born and Bred in Toronto; Toronto Global, 2022.
*Dollar amounts are in CAD unless specified otherwise.
*Professional technical and scientific services are an economic sector which includes engineering and related services.

# How U of T Drives the GTA's Quantum Capacity

**The GTA's Quantum Ecosystem**


Note that the organizations noted in this diagram are a selection of entitles involved in the quantum technologies and sciences ecosystem.

# How U of T Drives the GTA's Quantum Capacity continued

**Example of GTA's quantum capacity:**

- The GTA is home to 22 quantum startups, the most of any hub in Canada
- The Creative Destruction Lab, the country's only quantum-focused accelerator which has now graduated over 120 companies. Typically, the stream accepts 20-25 companies each year. CDL Quantum ventures collectively raised more than $300M and contributed to the creation of at least 290 jobs.

**Examples of U of T's quantum strengths:**

- Home to a dedicated quantum research centre, the Centre for Quantum Information and Quantum Control, as well as the Vector Institute, one of Canada's three research centres in artificial intelligence
- Success raising venture capital for quantum firms, including more than $148-million raised by U of T affiliated, quantum – focused, companies.
- One specialized quantum program at the graduate-level that is developing the next generation of quantum-literate talent;
- Over 35 quantum researchers who are addressing intractable problems in quantum computing, algorithms, communication, cryptography, metrology and control;
- U of T's leading quantum researchers earn the most quantum research awards and produce the most impactful (i.e., most cited) quantum publications when compared to several other Canadian universities

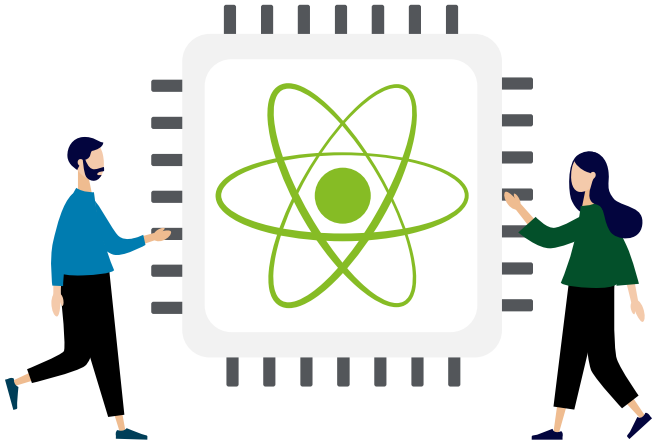
Sources: Toronto Global; Key Industries, Invest Vancouver, 2022; Waterloo EDC, 2022; New Report Reveals Worrying Trends About Funding in Waterloo Region, Betakit, 2022; CBRE, CBRE Tech Talent Rankings, 2022. Startup Genome, Toronto-Waterloo, 2022. Toronto, the Quietly Booming Tech Town, New York Times, 2022

Source：University of Toronto, 2022.

# U of T is Helping to Shape the Next Generation of Quantum Companies in Canada

**In the last decade, at least 12 quantum companies have been founded by U of T alumni and faculty.**

These companies account for at least 200 jobs in the GTA and have raised more than $300 million over the last decade.



AQT
Aurora
agnostiq
Entangled Networks
ENTROPICA LABS
LORICA CYBERSECURITY
ORCA Computing
OTI
QBT
Quantum Technologies
XANADU
ZAPATA

Sources: Pitchbook Database 2022, Crunchbase 2022, University of Toronto, 2022
*Company descriptions are taken directly from each company's website and Deloitte has not verified the information. Companies noted here self-identify as quantum related. Affiliated refers to companies that could be started by U of T alumni or, have graduated through CDL or other U of T entrepreneurship programs.

# An Investment in the GTA Quantum Ecosystem Can Help Position Canada to Achieve its Quantum Goals

U of T is investing to further scale its quantum capabilities through the recruitment of world-renowned quantum researchers, supporting cross-divisional and highly interdisciplinary research

The U of T is also working with industry partners to develop a private-public partnership to support talent development, knowledge translation, applied research and development, and commercialization in this emerging field.

# Appendix

# Over the Last 20-years, U of T Faculty Have Been at the Forefront of Quantum Research

**Over 35 quantum researchers are addressing intractable problems that can drive important commercial applications**

| | Quantum Computing | Quantum Communications and Cryptography | Quantum Sensing and Metrology | Quantum Imaging | Quantum Materials | Quantum Simulation |
|---|---|---|---|---|---|---|
| Key examples: **Focus area of research** | Quantum Computing and Algorithms | Quantum Security & Communication | Quantum Sensors for GPS | Medical Imaging / 3D imaging | Condensed Matter & Nanosystems | Quantum Simulation & Fundamental Quantum Information Science |
| Key examples: **Platform Technologies Developed** | Software | Photons | Photons | Atoms & Molecules | Atoms & Molecules | Atoms & Molecules |
| Key examples: **U of T researchers - commercialized products** | Quantum Algorithms | Quantum Fingerprinting Protocol | Single photon light source | Multiplexed Genetic Detection with Isothermal Signal Amplification | Quantum Dot Barcode Smartphone Optical Device | Quantum simulation software |

Sources: University of Toronto Analysis, 2022; Deloitte Analysis , 2022

# Global Research Output in Quantum Science and Technology

## Canada is among the Top 5 countries in the impact of its research

Canada currently ranks at No. 4 in the world in the significance of its research (as measured by the citation impact of publications.)

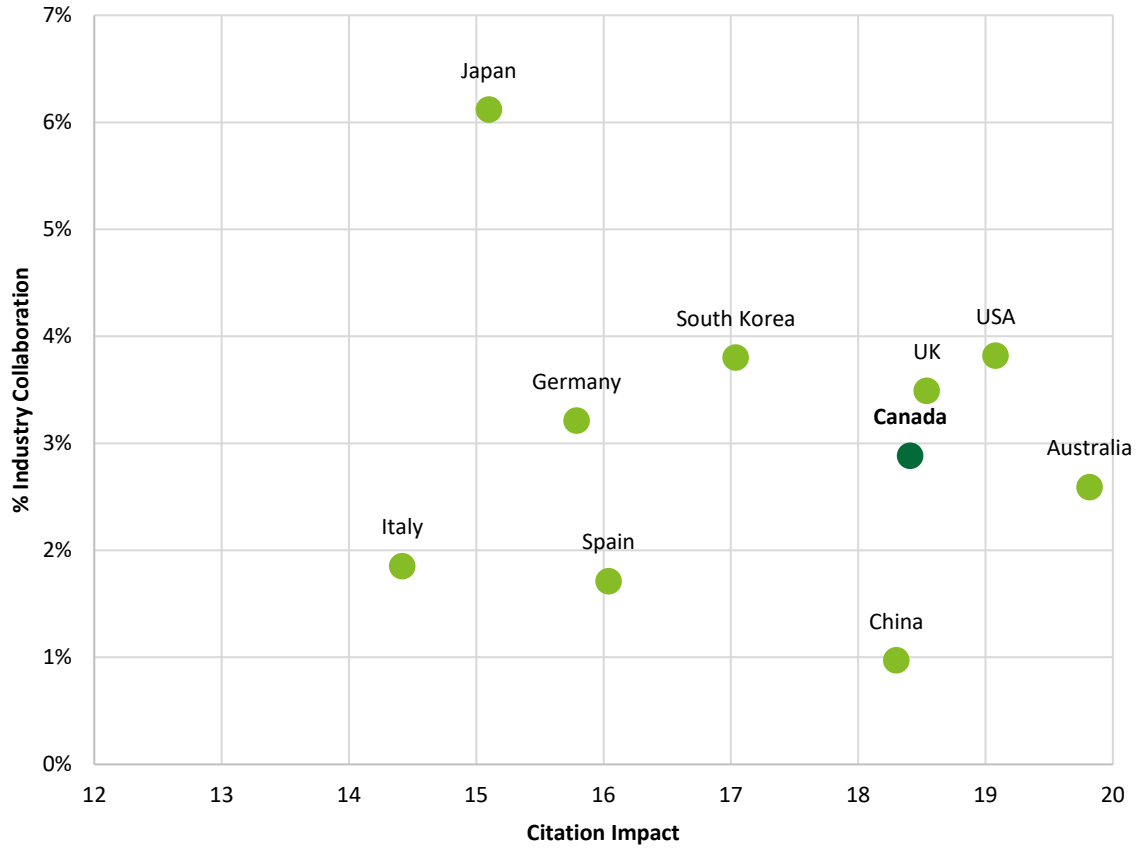
Japan, the U.S. and South Korea lead in the percentage of publications that feature collaboration with industry.

Among the top five countries in volume of research, China is leading in the number of quantum papers, overtaking the United States in 2015.

Notably, the impact of China's research continues to lag that of Australia, the U.S., the U.K., and Canada.

Between 2017 – 2021, many countries' rate of research output accelerated.

**Quantum research impact by country : 2017-2021**

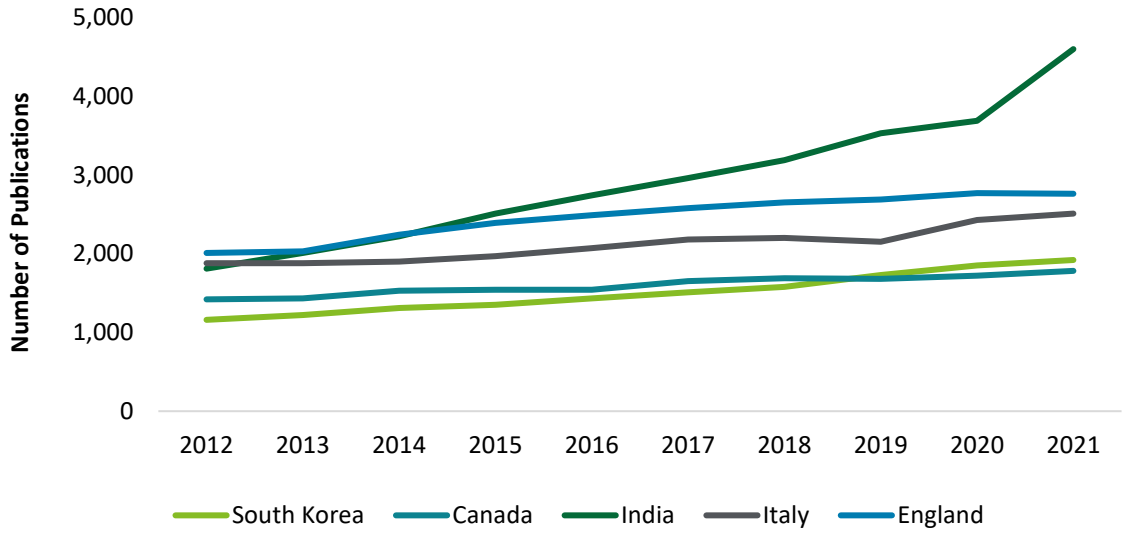



Data sources: The research impact of countries that are leading in the quantum research field is illustrated through two metrics: national citation ranking and the percentage of journal articles that have an industry co-author. Canada ranks at No. 4 for citation impact. This data has been sourced from the University of Toronto and not independently verified by Deloitte.

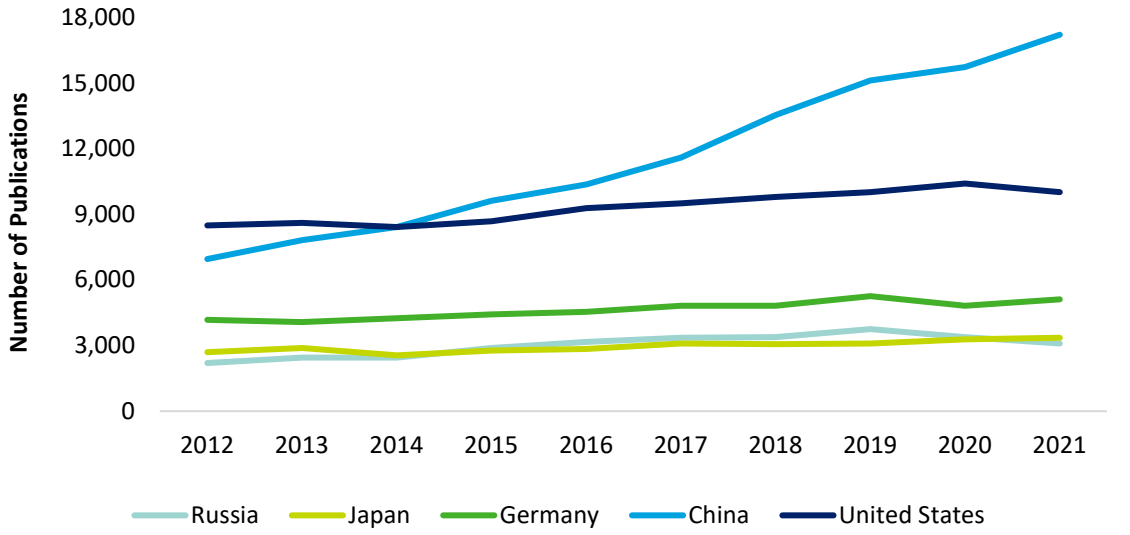
# Canada’s Quantum Science and Technology Research

- Between 2012 and 2021, Canada is 13th in terms of quantum papers produced with a total of 14,203 papers as seen in the graph bottom left below.
- Canada's rate of knowledge production has grown steadily.
- While this growth can be seen as positive, Canada’s peers are also accelerating research.
- India, for example, increased the number of publications by double digits most years between the period of 2012 – 2021.
- Canada's total percentage increase in that period was ~15 per cent, with the period of 2020 – 21 registering a 1 per cent decline.

**Number of quantum publications:**
**Canada and comparable countries, 2012 - 2021**




**Number of quantum publications:**
**Top 5 Countries by # of publications, 2012 - 2021**




Sources: Scientific American, China is Pulling Ahead in Global Quantum Race, New Studies Suggest. 2022; European Commission, Quantum Technologies Flagship 2022; Industry Canada, National Quantum Strategy 2022, University of Toronto Analysis, 2022.
Data sourced by the University of Toronto from Web of Science . Data has been provided by the University of Toronto and has not been validated and reviewed by Deloitte.

# Comparing the impact of quantum research at Canada's universities

## Quantum applications depend on advances in quantum science, an area where U of T has significant impact globally

The National Quantum Strategy recognizes that supporting Canada's "research base is essential to ensure leadership in quantum science and technology."

Reviewing the impact of research from universities which have a minimum publication volume of 1,000 journal articles between 2017 – 2021 shows Canada's research universities together rank in the top 50 institutions globally.

U of T ranks in the Top 5 universities in the world in the citation impact of its quantum research.

Three of the world's leading institutions are the leading producers of significant quantum research.

China has only one institution among the top 10 universities producing highly-cited quantum research, in spite of holding the No. 1 spot in the volume of research.

The University of Waterloo's rate of industry collaboration rivals that of the Massachusetts Institute of Technology (MIT).

U of T is only one of two public North American universities in the top 10 of producers of quantum research.

| Institution | Citation Impact | % Industry Collaboration |
|---|---|---|
| Harvard University | 39.27 | 4.60% |
| Massachusetts Institute of Technology (MIT) | 34.64 | 5.71% |
| Stanford University | 34.15 | 4.86% |
| Nanyang Technological University | 33.33 | 2.49% |
| University of Toronto | 32.65 | 4.26% |
| Princeton University | 32.43 | 6.06% |
| University of California Berkeley | 31.67 | 7.06% |
| Lawrence Berkeley National Laboratory | 31.11 | 3.35% |
| Soochow University - China | 30.83 | 1.23% |
| **University of Waterloo** | **18.71** | **5.55%** |
| **Canada's U15 Universities** | **19.56** | **2.89%** |

*Citation impact is defined as the average citations per paper published. The importance of a research paper is linked to how much it is cited by others and used in their own work, therefore citation impact is a metric of scientific importance.
Note: The data and analysis presented on this page has been provided by the University of Toronto. Deloitte has not independently verified the analysis or statistics shown herein.
Sources: Clarivate Web of Science data extracted by University of Toronto, 2023.
Since most papers have many co-authors, some papers might be listed twice or more depending on how many co-authors there is. To simplify, we understand number of papers published as, number of papers where an author is from the institution.
For further information please see Appendix 3

Deloitte.