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HOW CAN CANADA REMAIN A LEADER IN THE GLOBAL QUANTUM MARATHON?

Report of the Standing Committee on Industry and Technology

Joël Lightbound, Chair

SEPTEMBER 2022
44th PARLIAMENT, 1st SESSION

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NOTICE TO READER

Reports from committees presented to the House of Commons

Presenting a report to the House is the way a committee makes public its findings and recommendations on a particular topic. Substantive reports on a subject-matter study usually contain a synopsis of the testimony heard, the recommendations made by the committee, as well as the reasons for those recommendations.

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THE STANDING COMMITTEE ON INDUSTRY AND TECHNOLOGY

has the honour to present its

SIXTH REPORT

Pursuant to its mandate under Standing Order 108(2), the committee has studied Quantum Computing and has agreed to report the following:

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SUMMARY

In Canada, as well as around the world, governments, academia and private companies have been working hard for years to develop quantum technologies. These technologies could present incredible opportunities, but also major risks. For instance, when fully developed, which experts say will be in 10 to 20 years, quantum computers could, on the one hand, be used to break current cryptography, putting all online communications at risk, including banking and critical infrastructure systems. On the other hand, they could perform calculations that would take today's fastest supercomputers billions of years, making it possible to accelerate drug discovery, facilitate supply chain management or solve complex financial problems, for example.

Canada has been a leader in the development of quantum technologies for the past few decades, but faces some challenges in maintaining this position in the longer term. In addition, several countries, including the United States, France and the People's Republic of China have developed aggressive strategies to develop quantum technologies and are competing with Canada to develop the first fault-tolerant universal quantum computer.

The House of Commons Standing on Industry and Technology made 11 recommendations in its report to the Government of Canada. For instance, it recommended that it ensure that the National Quantum Strategy provides sufficient funding, in a strategic manner, to the various quantum industry stakeholders in Canada; that, as part of the National Quantum Strategy, it develop a coordinated approach to support the development and retention of quantum talent in Canada; and that it ensure that there is cohesion between the various initiatives and between the support offered to researchers and companies in order to build strong quantum ecosystems across the country. To protect different sectors from cyber threats arising from quantum technologies the Committee recommended that, in conjunction with stakeholders, it develop as quickly as possible a strategy to protect existing encryption systems at various levels.

LIST OF RECOMMENDATIONS

As a result of their deliberations committees may make recommendations which they include in their reports for the consideration of the House of Commons or the Government. Recommendations related to this study are listed below.

Recommendation 4

That, as part of the National Quantum Strategy, the Government of Canada, in coordination with the National Research Council Canada, the Canadian Security Intelligence Service and the Communications Security Establishment, and in conjunction with stakeholders in banking, power grids, nuclear facilities, government communications, military communications and other affected industries, develop as quickly as possible a strategy to protect existing encryption systems at various levels:

- **in the short term to ensure that data is not stored by malicious groups or organizations; and**
- **in the longer term to protect systems from risks posed by quantum computing.** 47

Recommendation 5

That, as part of the National Quantum Strategy, the Government of Canada put the necessary investments in place to build a robust and resilient supply chain for advanced materials and to develop commercial manufacturing capacity for these materials in Canada in order to support the continued growth of advanced technology industries. This will also be a step toward digital sovereignty in order to protect the industry from risks posed by reliance on supply chains outside Canada. 48

Recommendation 6

That, as part of the National Quantum Strategy, the Government of Canada develop a coordinated approach to support the development and retention of quantum talent in Canada. This approach could include:

- **implementing initiatives to boost the participation of under-represented groups in the sciences, including racialized people, women and Indigenous people;**
- **establishing, in collaboration with universities, a national quantum training program to support the development of quantum expertise, attract international talent and foster collaboration among researchers across the country;**

HOW CAN CANADA REMAIN A LEADER IN THE GLOBAL QUANTUM MARATHON?

INTRODUCTION

On 1 March 2022, the House of Commons Standing Committee on Industry and Technology agreed to undertake a study on quantum computing to understand the opportunities and risks associated with it and to have "an overview of the domestic quantum computing industry and measures taken to ensure Canada retain its talent and competitive advantages."[1] In the course of its study, the Committee heard from 20 witnesses and received two briefs between March and April 2022.

OVERVIEW OF QUANTUM COMPUTING

The Technology

Thanks to properties derived from the behaviour of matter on the atomic and subatomic scale, quantum systems can be very powerful. Whereas classical systems encode data using binary signals (0 or 1), measured in bits, quantum systems use signals measured in qubits, which can have a value of 0, 1 or both at the same time (superposition). Superposition is what gives quantum systems their power because it allows them to perform multiple calculations simultaneously. By controlling particle behaviour, researchers can manipulate the particles to encode them, enabling various applications. Currently, it is difficult to manipulate and encode qubits because they are highly unstable. As soon as a disturbance occurs, the qubit's superposition collapses, destroying the encoded information. Qubits must therefore be isolated from their environment using various methods in order to be manipulated. Because of this instability, quantum systems can currently be operated only in laboratories.[2]

Quantum computers are a tool that uses quantum mechanics to manipulate information. Since research is still at the exploratory phase, the quantum computers that have been developed so far have different characteristics based on the system used to

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1 House of Commons, Standing Committee on Industry and Technology [INDU], *Minutes*, Meeting 10, 1 March 2022.

2 Johnny Kung and Muriam Fancy, *A Quantum Revolution: Report on Global Policies for Quantum Technology*, Canadian Institute for Advanced Research (CIFAR), April 2021; and Catherine Florès, "Les constructeurs de l'avenir quantique," *Magazine Poly*, Polytechnique Montréal, 1 March 2019 [AVAILABLE IN FRENCH ONLY].

design them, each with its own advantages and disadvantages.[3] Ultimately, researchers want to develop a universal quantum computer that will no longer be sensitive to faults caused by the instability of qubits. Witnesses said that researchers have made significant breakthroughs in recent years and are getting closer and closer.[4]

One of the most interesting characteristics of quantum computers is the speed at which they can process information. Qubit superposition enables quantum computers to perform multiple actions simultaneously, which explains why a quantum computer has so much computing power.[5] A quantum computer will not be more efficient than a classical computer in all aspects, but it will be able to perform some calculations considerably faster.[6] Alexandre Blais, Professor and Scientific Director at the University of Sherbrooke's Quantum Institute, said: "A quantum computer could indeed efficiently complete computations that would take billions of years with today's fastest supercomputers."[7] For example, it could accelerate and optimize drug discovery and material discovery.[8] It could also help solve complex financial problems.[9] From a medical perspective, Jaron Chong, from the Canadian Association of Radiologists, added:

> There is some theoretical work that would suggest that if we can convert some of these training problems for neural networks into a quantum computable problem, the same benefits that you would have for decrypting an encrypted message could actually be applied for the training of a neural network. That would enable you to run multiple computations simultaneously and vastly accelerate your training time.[10]

3 INDU, *Evidence*, 29 March 2022, 1540 (Raymond Laflamme, As an individual), INDU, *Evidence*, 1 April 2022, 1320 (Allison Schwartz, D-Wave Systems Inc. (D-Wave)).

4 INDU, *Evidence*, 25 March 2022, 1405 (Alexandra Blais, As an individual), INDU, *Evidence*, 25 March 2022, 1410 (Norbert Lütkenhaus, As an individual) INDU, *Evidence*, 1 April 2022, 1305 (Anne Broadbent, As an individual).

5 Johnny Kung and Muriam Fancy, *A Quantum Revolution: Report on Global Policies for Quantum Technology*, Canadian Institute for Advanced Research (CIFAR), April 2021; and Catherine Florès, "Les constructeurs de l'avenir quantique," *Magazine Poly*, Polytechnique Montréal, 1 March 2019 [AVAILABLE IN FRENCH ONLY].

6 INDU, *Evidence*, 25 March 2022, 1405 (Blais), INDU, *Evidence*, 29 March 2022, 1555 (Rafal Janik, Xanadu Quantum Technologies Inc.), INDU, *Evidence*, 29 March 2022, 1545 (Alireza Yazdi, Anyon Systems Inc.), INDU, *Evidence*, 5 April 2022, 1650 (Gilles Brassard, As an individual), IBM Canada, *Brief*.

7 INDU, *Evidence*, 25 March 2022, 1405 (Blais).

8 INDU, *Evidence*, 1 April 2022, 1425 (Stéphanie Simmons, Photonic Inc.), INDU, *Evidence*, 5 April 2022, 1530 (Brassard), INDU, *Evidence*, 5 April 2022, 1550 (Jaron Chong, Canadian Association of Radiologists), IBM Canada, *Brief*.

9 INDU, *Evidence*, 5 April 2022, 1610 (Brassard), IBM Canada, *Brief*.

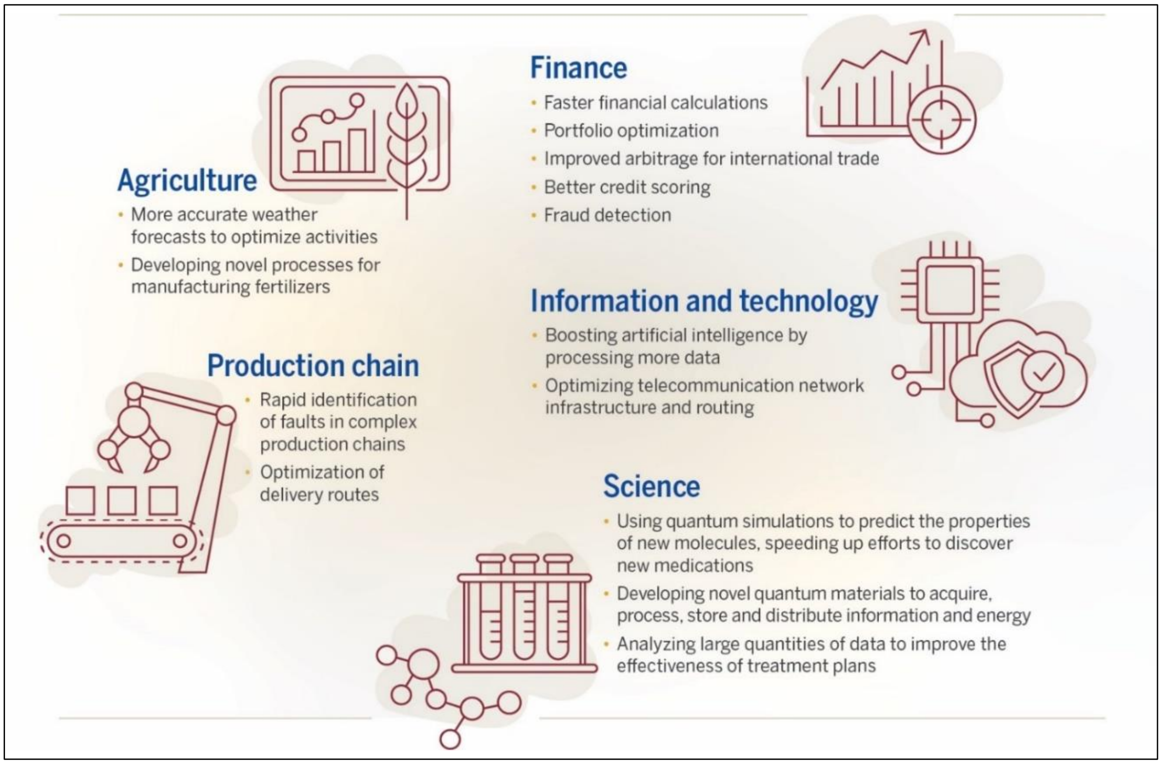
10 INDU, *Evidence*, 5 April 2022, 1615 (Chong).

> **"A quantum computer could indeed efficiently complete computations that would take billions of years with today's fastest supercomputers."**

Quantum computers will be particularly useful for solving combinatorics problems, which are problems that involve finding the optimal way to arrange a set of objects. In these problems, the number of arrangements grows exponentially each time an object is added, increasing the complexity of the problem. The more complex these problems are, the longer it takes for a classical computer to solve them, because it must try every possible permutation in order to find the right one, unlike a quantum computer, which can perform these tasks simultaneously.[11] Solving these types of problems much more quickly will save companies significant costs, as many activities in various sectors are in fact combinatorics problems. Figure 1 shows examples of combinatorics problems in various sectors that quantum computers could solve.

11 Francesco Bova, Avi Goldfarb and Roger Melko, *Quantum Computing is Coming. What can it do?*, Harvard Business Review, 16 July 2021.

Figure 1—Examples of Combinatorics Problems in Various Sectors that Quantum Computers Could Solve



Sources: Figure prepared by the Library of Parliament using information obtained from Francesco Bova, Avi Goldfarb and Roger Melko, "Commercial applications of quantum computing," *EPJ Quantum Technology*, Vol. 8, No. 2, 2021; Francesco Bova, Avi Goldfarb and Roger Melko, Quantum Computing Is Coming. What Can It Do?, *Harvard Business Review*, 16 July 2021; and Marc Haddad et al., *Quantum Computing: A technology of the future already present*, PricewaterhouseCoopers, 2019.

Witnesses discussed the potential impact of quantum computing on artificial intelligence (AI). In recent years, with increased computing power and availability of vast datasets (big data), the most common application of AI is machine learning. Rather than being programmed to solve a problem using logical instructions, machine learning algorithms crunch data and then extract patterns, providing better performance.[12] Raymond Laflamme, Canada Research Chair in Quantum Computing, believes it's too early in the development of quantum computing to predict its impact on AI.[13]

12 Matthew Smith and Sujaya Neupane, *Artificial intelligence and human development: toward a research agenda*, International Development Research Centre, April 2018, p. 103.

13 INDU, *Evidence*, 29 March 2022, 1725 (Laflamme).

Rafal Janik, from Xanadu Quantum Technologies Inc., believes that quantum computing will accelerate machine learning and other AI applications, but only in 10 to 20 years.[14]

The complexity of quantum computing makes developing this industry a long-term endeavour. Witnesses believe that an error-tolerant quantum computer would be available in about 10 years.[15] Stéphanie Simmons, of Photonic Inc., believes that it could be available much sooner than experts predict.[16] Dr. Laflamme added that a Ph.D. takes about five years to complete, but building a quantum computer takes even longer.[17] Because of the long timeframe, witnesses stressed the importance for the federal government to support the long-term development of full quantum systems in Canada, including talent development and research at many levels.[18] Norbert Lütkenhaus, Executive Director of the Institute for Quantum Computing, said: "Always remember, if you like cherries, you need to plant a cherry tree. You can't grow the cherries directly. There is a whole system that you need."[19]

Despite this long-term development, quantum technologies can be useful in the short term. For example, Alison Schwartz from D-Wave Systems Inc. said that, in 2020, D-Wave released their *Advantage* quantum systems, a hybrid solver service that combines classical and quantum computing technologies via the cloud. She believes that the cloud is "another key tool to promote inclusive and diverse use of the technology."[20] Ms. Schwartz wondered why the federal government isn't using the quantum technologies available today to solve complex problems as other countries are doing. For example, Japan is considering using them for "piloting and for tsunami evacuation route optimization, as well as [to] reduce CO2 emissions during waste collection."[21] Andrew Fursman, from 1QB Information Technologies Inc., disagreed, saying that quantum computers are not yet developed enough to be used outside of research centres.[22]

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14 INDU, *Evidence*, 29 March 2022, 1730 (Janik).

15 INDU, *Evidence*, 29 March 2022, 1615 (Laflamme), INDU, *Evidence*, 29 March 2022, 1650 (Yazdi), INDU, *Evidence*, 5 April 2022, 1610 (Brassard).

16 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

17 INDU, *Evidence*, 29 March 2022, 1700 (Laflamme).

18 INDU, *Evidence*, 1 April 2022, 1315 (Andrew Fursman, 1QB Information Technologies Inc.), INDU, *Evidence*, 25 March 2022, 1415 (Lütkenhaus).

19 INDU, *Evidence*, 25 March 2022, 1415 (Lütkenhaus).

20 INDU, *Evidence*, 1 April 2022, 1320 (Schwartz).

21 INDU, *Evidence*, 1 April 2022, 1440 (Schwartz).

22 INDU, *Evidence*, 1 April 2022, 1320 (Fursman).

State of Development

Canada has historically been a leader in quantum technologies.[23] Nipun Vats, the Assistant Deputy Minister of the Science and Research Sector at Innovation, Science and Economic Development Canada, said that Canada's strengths in quantum technologies include quantum computing, quantum communications and quantum cryptography. He noted that, over the past 10 years, the federal government has invested over $1 billion in various projects in the Canadian quantum ecosystem.[24] He believes Canada is a leader in quantum science because of the country's long-term investments in basic and applied research that have helped Canadian researchers lead the development of innovations in quantum science.[25] Dr. Blais also believes that this funding has helped Canadian researchers, but added that "[l]ooking back, one can almost say that Canada's position in quantum research was reached by luck. It is the efforts of individual researchers and institutions using existing competitive programs."[26]

According to Dr. Vats, Canada's ecosystem of quantum technologies is growing rapidly. One of the reasons for this is that there are centres of quantum expertise in universities across the country and healthy private-sector investment in the industry. In fact, some Canadian companies have achieved quantum world firsts. Table 1 shows quantum work in the four major centres of quantum expertise across the country. Dr. Vats said that the strengths of each of these regions are complementary and that collaborations between researchers across the country would position Canada's quantum ecosystem well for future success.[27] He also pointed out that, due to the complexity of quantum technologies, they cannot all be developed in any one country, underscoring the need for international collaborations. However, these collaborations generally occur at the researcher, not country, level.[28] Dr. Laflamme added that, in the last five years, researchers have been working to develop applications for different industries.[29] He

23 INDU, *Evidence*, 25 March 2022, 1305 (Nipun Vats, Innovation, Science and Economic development Canada), INDU, *Evidence*, 29 March 2022, 1540 (Laflamme), INDU, *Evidence*, 5 April 2022, 1530 (Brassard).

24 INDU, *Evidence*, 25 March 2022, 1305 (Vats).

25 INDU, *Evidence*, 25 March 2022, 1305 (Vats).

26 INDU, *Evidence*, 25 March 2022, 1405 (Blais).

27 INDU, *Evidence*, 25 March 2022, 1305 (Vats).

28 Ibid.

29 INDU, *Evidence*, 29 March 2022, 1615 (Laflamme).

believes that "[q]uantum information science and technology is an incredible opportunity for Canada."[30]

Table 1—Examples of Quantum Work in the four major centres of quantum expertise in Canada

Region	Examples of Quantum Work
Toronto–Waterloo	• Quantum information, communications and sensors, with commercialization accelerators and incubators, including companies like Xanadu and Ranovus. • The Institute for Quantum Computing, housed at the University of Waterloo, is the largest institution of its kind in the world.
Greater Montreal–Sherbrooke–Quebec City corridor	• Quantum hardware and devices. • Companies include IBM, Anyon Systems and SB Quantum.
Calgary–Edmonton corridor	• Nanotechnology and enabling technologies. • Alberta is building a provincial quantum network, Quantum Alberta, to encourage and accelerate the commercialization of quantum technologies.
Greater Vancouver	• Quantum algorithms and hardware development. Quantum BC plays a key role in convening provincial stakeholders. • A local B.C. company, D-Wave, was an early leader globally in quantum computing and has made significant strides recently in terms of investment and commercialization of its technologies.

Source: Table prepared by the Library of Parliament using information obtained from INDU, *Evidence*, 25 March 2022, 1305 (Vats).

National Quantum Strategy

Dr. Vats said that, given this context, in its 2021 Budget, the Government of Canada proposed $360 million over seven years starting in 2021–2022 to launch a National Quantum Strategy (NQS). According to the Government of Canada, the strategy will "amplify Canada's significant strength in quantum research; grow our quantum-ready technologies, companies, and talent; and solidify Canada's global leadership in this

30 INDU, *Evidence*, 29 March 2022, 1540 (Laflamme).

area."[31] Between July and October 2021, Innovation, Science and Economic Development Canada (ISED) held virtual roundtables and an online survey to gather the views of different stakeholders on various aspects of the national quantum strategy such as research, commercialization, security and the international context.[32] In its report on its findings, ISED concluded that, for Canada to remain a leader in quantum, both domestic and international collaboration between academia, industry and government are essential.[33]

"[Q]uantum information science and technology is an incredible opportunity for Canada."

In response to questions about the NQS, Dr. Vats made several comments. He said that, in determining the framework for the NQS, the federal government consulted extensively with stakeholders. It also worked with provincial governments to make sure that the NQS was complementing what they were already doing.[34] Dr. Vats added that there was no official date for the announcement of the final NQS strategy document, but that funding under the strategy had already begun to flow. He also expected stakeholders to find the $360 million in funding alone to be insufficient for the industry's needs. However, he said that this funding was in addition to the hundreds of millions already invested and being invested through other programs. Further, that the federal government was looking to focus its funding so as to be more competitive internationally. He said that targeted funding is needed to accelerate development because there is a huge gap between building a quantum computer on a small scale in the lab and building one on a commercial scale.[35]

Witnesses agreed on the importance of the federal government making strategic choices in developing the NQS. Witnesses said that Canada has not yet made strategic choices through the NQS, which allows researchers to explore different avenues and technologies.[36] However, some cautioned that the NQS cannot scatter the dollars all over in the long term. The federal government has difficult but necessary choices to

31 *Budget 2021*. INDU, *Evidence*, 25 March 2022, 1305 (Vats).

32 Government of Canada, *National Quantum Strategy*.

33 INDU, *Evidence*, 25 March 2022, 1305 (Vats).

34 INDU, *Evidence*, 25 March 2022, 1320 (Vats).

35 Ibid., 1325.

36 INDU, *Evidence*, 25 March 2022, 1425 (Blais), INDU, *Evidence*, 5 April 2022, 1620 (Brassard).

make to maximize resources.[37] Dr. Lütkenhaus added that the NQS's approach should be to make strategic choices to bring together researchers around common goals. If these goals attract enough interest from Canadian researchers, there is a chance for research done in Canada to have a large impact internationally.[38]

Witnesses were uncertain about the best time to invest in a particular technology or technologies. Dr. Vats said it was too early in the quantum computer "race" to pick winners. He suggested that one or two winning technologies would likely emerge.[39] Witnesses agreed and said it was difficult to predict when the technologies will be ripe enough for the federal government to make decisions. They hoped that by the end of the seven-year NQS funding period the government would be able to make a decision.[40] For her part, Dr. Simmons said that the dominant design for quantum will become apparent in the next few years.[41] She added that choosing approaches before the winning design emerges entails some risk, but the risk of waiting to invest in one or more winning approaches is much greater.[42]

Ultimately, it's possible that more than one technology will be used to develop and work with the quantum computer. Mr. Janik does not believe that any single technology will prevail.[43] According to IBM Canada, a combination of classical and quantum computing will fuel the predicted breakthroughs.[44] Ms. Schwartz believed the federal government should support quantum hybrid technology because, when developed, quantum computers will not replace classical computers but will be used together, depending on the application.[45] She added that cloud access will also be useful in the long run, as she believed it will help identify possible applications of quantum hybrid technologies. Small start-ups will also be able to develop their systems through a cloud.[46] She added that creating a national computing centre would help develop the technologies:

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37 INDU, *Evidence*, 25 March 2022, 1500 (Blais), INDU, *Evidence*, 25 March 2022, 1540 (Laflamme), INDU, *Evidence*, 1 April 2022, 1310 (Edward McCauley, As an individual).

38 INDU, *Evidence*, 25 March 2022, 1425 (Blais), INDU, *Evidence*, 25 March 2022, 1425 (Lütkenhaus).

39 INDU, *Evidence*, 25 March 2022, 1350 (Vats).

40 INDU, *Evidence*, 29 March 2022, 1655 (Laflamme), INDU, *Evidence*, 29 March 2022, 1655 (Yazdi).

41 INDU, *Evidence*, 1 April 2022, 1325 (Simmons).

42 INDU, *Evidence*, 1 April 2022, 1325 (Simmons).

43 INDU, *Evidence*, 29 March 2022, 1555 (Janik).

44 IBM Canada, *Brief*.

45 INDU, *Evidence*, 1 April 2022, 1320 (Schwartz) , D-Wave, *Brief*.

46 INDU, *Evidence*, 1 April 2022, 1500 (Schwartz).

> If there were a domestic high-performance computing centre integrated with quantum, you could have some quantum systems there, and in a variety of sizes. Maybe some of them are the smaller ones that are really looked at just for research, and others could be commercial-sized ones and navigate through that. From the government's perspective, I don't think it's an "or". I think it's an "and" …[47]

To help the federal government make strategic decisions, Dr. Blais proposed building on an initiative in the United States. He explained that two research funding agencies send challenges out to the community. These challenges are issued by actors in the community, to which the community can respond. These challenges must involve multiple research teams across the country and can include participants in foreign countries. The University of Sherbrooke group receives funding for participating in these challenges. The community then makes the strategic choices by proposing the avenues it thinks are the most promising. Then, in collaboration with the funding agencies, the choices are made, and funding is granted.[48]

Finally, in order to implement strategic choices through the NQS, witnesses also proposed building on Canada's strengths. Olivier Gagnon-Gordillo, Québec Quantique, proposed investing in strong industrial sectors in Canada based on the strengths of each province. The government could then focus on one or two of these sectors per province and find early adopters who could lead the way in Canada's adoption of quantum technology. He said this would also bridge the gap between basic and applied research.[49] Other witnesses said that Canada should build on its current strengths and priorities in coordination with the quantum industry, for example national security and cybersecurity.[50] Mr. Fursman added that there is a need for long-term investment and a need to define success.[51]

> **"To make an impact on the global stage, Canada needs an agile, ambitious [national quantum strategy]."**

47 INDU, *Evidence*, 1 April 2022, 1500 (Schwartz).

48 INDU, *Evidence*, 25 March 2022, 1425 (Blais).

49 INDU, *Evidence*, 5 April 2022, 1730 (Olivier Gagnon-Gordillo, Québec Quantique).

50 INDU, *Evidence*, 25 March 2022, 1505 (Lütkenhaus), INDU, *Evidence*, 1 April 2022, 1310 (McCauley).

51 INDU, *Evidence*, 1 April 2022, 1440 (Fursman).

Funding

Witnesses did not believe the $360 million in funding announced for the NQS would be enough to support the quantum industry in C make an impact on the global stage, Canada needs anada. They noted that this funding was an excellent effort but modest compared to other countries.[52] Canada's quantum industry needs more funding to maintain its position as a world leader.[53] It needs direct, predictable funding to develop the technology.[54] It also needs longer-term support, as it takes about 15 years to develop a quantum technology company.[55] Mr. Fursman added that it may be hard to summon the political will to support the industry since it is not yet competitive against traditional computers, but that "the infant industry argument is one of the most solid economic cases for government investment."[56]

Several countries are now investing heavily in developing their quantum expertise.[57] Professor and University Research Chair in Quantum Information and Cryptography, Anne Broadbent, said that several countries, including Germany, the United States, France, the People's Republic of China (PRC) and the United Kingdom have aggressive strategies to develop quantum technologies.[58] Witnesses said that there's a global race to develop quantum technologies and, because it's a long-term effort, it's a marathon, not a sprint.[59] Mr. Gagnon-Gordillo said that Canada "is often listed in the top five [countries in quantum computing]" but it's a fragile position that highlights the importance of making strategic investments.[60] To make an impact on the global stage,

52 INDU, *Evidence*, 25 March 2022, 1405 (Blais), INDU, *Evidence*, 1 April 2022, 1310 (McCauley), INDU, *Evidence*, 5 April 2022, 1730 (Brassard), INDU, *Evidence*, 5 April 2022, 1730 (Marie-Pierre Ippersiel, PRIMA Québec).

53 INDU, *Evidence*, 29 March 2022, 1550 (Philippe St-Jean, Nord Quantique), INDU, *Evidence*, 1 April 2022, 1355 (McCauley), INDU, *Evidence*, 29 March 2022, 1625 (Yazdi).

54 INDU, *Evidence*, 1 April 2022, 1320 (Fursman).

55 INDU, *Evidence*, 5 April 2022, 1715 (Gagnon-Gordillo).

56 INDU, *Evidence*, 1 April 2022, 1315 (Fursman).

57 INDU, *Evidence*, 25 March 2022, 1405 (Blais), INDU, *Evidence*, 29 March 2022, 1540 (Laflamme), INDU, *Evidence*, 1 April 2022, 1305 (Broadbent), INDU, *Evidence*, 1 April 2022, 1310 (McCauley).

58 INDU, *Evidence*, 1 April 2022, 1305 (Broadbent).

59 INDU, *Evidence*, 29 March 2022, 1540 (Laflamme), INDU, *Evidence*, 1 April 2022, 1320 (Fursman), INDU, *Evidence*, 5 April 2022, 1605(Gagnon-Gordillo).

60 INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo).

Canada needs an agile, ambitious NQS so it can make strategic choices, since it cannot excel in all areas.[61]

> **"[I]t's a question of whether Canada can fund 'the full story'."**

Other witnesses felt that Canada could be well positioned in this race. Philippe St-Jean, Nord Quantique, said that collaboration between Canadian researchers has allowed Canada to remain competitive until now despite considerable investment by its international competitors in their quantum sectors. He believed that the first quantum computer would emerge in Canada or the United States but added that Canada must act now if it wants a chance to succeed.[62] IBM Canada added that:

> to gain a true competitive advantage in the race to develop quantum technologies, Canada has various enviable intangibles: a highly skilled, diverse workforce; a renowned and vibrant research community; an innovation-centric approach; and finally, a genuine resolve to forge ahead. These ingredients only need to be supplemented by bold, ambitious funding streams, to sustain the investments made by provinces, research, and private interests.[63]

The NQS should provide funding for all stages of technology development, from basic research to commercialization. All stages need funding.[64] For example, funding is needed to support basic research and build research infrastructure, which is very expensive.[65] Dr. Simmons said that, because Canadian professors do not receive enough funding for their research, they have to look at external support from domestic and international organizations.[66] Funding is also needed to translate this research into commercial success.[67] Mr. Gagnon-Gordillo noted that start-ups often have enough funding to start their work, but often lack the support to scale up and therefore have to seek foreign investors.[68] Physics professor Kimberly Hall said that basic research and commercial innovation are much more tightly linked in the quantum area than in any other field, as

61 INDU, *Evidence*, 25 March 2022, 1405 (Blais), INDU, *Evidence*, 25 March 2022, 1605 (Gagnon-Gordillo).

62 INDU, *Evidence*, 29 March 2022, 1550 (St-Jean).

63 IBM Canada, *Brief*.

64 INDU, *Evidence*, 29 March 2022, 1640 (St-Jean), INDU, *Evidence*, 5 April 2022, 1730 (Ippersiel).

65 INDU, *Evidence*, 25 March 2022, 1410, 1425 (Lütkenhaus), INDU, *Evidence*, 5 April 2022, 1620 (Brassard).

66 INDU, *Evidence*, 1 April 2022, 1425 (Simmons).

67 INDU, *Evidence*, 29 March 2022, 1550 (St-Jean), INDU, *Evidence*, 29 March 2022, 1625 (Janik), INDU, *Evidence*, 29 March 2022, 1620 (Laflamme).

68 INDU, *Evidence*, 5 April 2022, 1715, 1730 (Gagnon-Gordillo).

companies are formed around concepts that are promising.[69] Dr. St-Jean added that ultimately it's a question of whether Canada can fund "the full story."[70]

Witnesses offered various examples to illustrate the funding needed to develop the quantum computer and its industry. Dr. Laflamme said that it costs between $50 and $100 million to build a quantum research lab and hundreds of millions, if not billions, to build production facilities to commercialize a quantum computer.[71] Mr. Janik agreed.[72] He added that Xanadu has been able to raise $175 million to build a fault-tolerant universal quantum computer, but that is only about 20% of what is needed to create this computer.[73]

As a financial arm of the government, the Business Development Bank of Canada could play an important role in supporting companies in advanced materials and quantum technologies. In venture capital, it acts either through its own funds or as a government agent to invest in the various funds set up. It also acts by investing directly in companies.

EMERGING CYBERSECURITY RISKS

Once fully developed, quantum computing could break current cryptography. Professor Gilles Brassard said "quantum computing poses a very significant threat to security."[74] It is urgent for everyone to be concerned about the risks posed by quantum computing, since it will be able to break all current cryptography encryption systems.[75] Witnesses explained that it will be able to break the modern encryption system that uses an asymmetric cryptography algorithm (RSA), which is used almost everywhere, including for online communications, social media platforms, banking, critical infrastructure such as power grids and nuclear facilities, and government and military communications. All businesses with an online presence will be affected.[76] All current encryption systems will

69 INDU, *Evidence*, 5 April 2022, 1545 (Kimberly Hall, As an individual).

70 INDU, *Evidence*, 29 March 2022, 1625 (St-Jean).

71 INDU, *Evidence*, 29 March 2022, 1610 (Laflamme).

72 INDU, *Evidence*, 29 March 2022, 1700 (Janik).

73 Ibid., 1625.

74 INDU, *Evidence*, 5 April 2022, 1530 (Brassard).

75 INDU, *Evidence*, 29 March 2022, 1630 (Laflamme), INDU, *Evidence*, 1 April 2022, 1330 (Simmons), INDU, *Evidence*, 5 April 2022, 1530 (Brassard), INDU, *Evidence*, 5 April 2022, 1535 (Shohini Ghose, As an individual).

76 INDU, *Evidence*, 1 April 2022, 1305 (Broadbent), INDU, *Evidence*, 1 April 2022, 1315, 1450 (Simmons).

have to be replaced.[77] The risk posed by quantum computing is asymmetric because, as soon as a single quantum computer is able to break the RSA, all encryption will be obsolete.[78] Some witnesses think that this could happen in about 10 to 20 years.[79]

> **“[Q]uantum computing poses a very significant threat to security.”**

Dr. Simmons, meanwhile, thinks that a quantum computer capable of breaking current encryption systems could be available well within 10 years.[80] She said that the history of nuclear fission illustrates her point:

> In 1933, the world’s leading nuclear physicist, Rutherford, ridiculed the idea of ever getting energy from nuclear transmutations. That was the predominant scientific view at the time; if it weren’t impossible, it was at least 20 to 30 years away. However, it was a mere seven years between the demonstration of nuclear fission a few years later in 1938 and the first nuclear bomb explosion. This is the power of a dominant design and a Manhattan-like mobilization to organize and bring it into reality. We at Photonic believe that quantum technologies are much closer than they currently appear.[81]

The development of a quantum computer could therefore pose significant national security risks. Dr. Laflamme believes the relationship between quantum computing and national security is obvious.[82] According to Dr. Simmons, “[e]ssentially, unless we defend our cybersecurity infrastructure properly now, the advent of a quantum computer could be positioned as the information-security equivalent of the nuclear bomb.”[83] Dr. Yazdi believes that the sooner Canada can improve its encryption infrastructure, the better it is for the country’s security.[84]

77 INDU, *Evidence*, 1 April 2022, 1325 (Simmons).

78 INDU, *Evidence*, 1 April 2022, 1325, 1405 (Simmons).

79 INDU, *Evidence*, 29 March 2022, 1630, 1645 (Laflamme), INDU, *Evidence*, 29 March 2022, 1650 (Yazdi), INDU, *Evidence*, 5 April 2022, 1610 (Brassard), INDU, *Evidence*, 1 April 2022, 1325 (Simmons).

80 INDU, *Evidence*, 1 April 2022, 1340 (Simmons).

81 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

82 INDU, *Evidence*, 29 March 2022, 1645 (Laflamme).

83 INDU, *Evidence*, 1 April 2022, 1325 (Simmons).

84 INDU, *Evidence*, 29 March 2022, 1650 (Yazdi).

Short-Term Risks

Witnesses explained that various entities may be storing information right now with a view to decrypting it later when a quantum computer becomes available. A quantum computer could provide unheard of access to all modern and stored communications.[85] This poses significant risks if other countries store information for future decryption.[86]

> **"[U]nless we defend our cybersecurity infrastructure properly now, the advent of a quantum computer could be positioned as the information-security equivalent of the nuclear bomb."**

Witnesses discussed the importance of developing and implementing new encryption algorithms to protect systems from the power of quantum computing. Several witnesses suggested that the federal government and all organizations with an online presence should stop using old encryption algorithms and consider implementing new algorithms now.[87] The need to act is urgent, as new encryption algorithms must be in place before the emergence of the quantum computer, and it will likely take years to implement adequate algorithms to protect all current encryption, especially in the financial sector.[88] Dr. Simmons said that encryption algorithms for critical infrastructure like power grids and nuclear facilities are especially in need of protection.[89] Dr. Brassard also stressed the importance of educating people about the risks ahead.[90] Dr. Simmons added that the federal government should find a regulatory way to encourage businesses to invest in new encryption algorithms.[91]

Researchers have already begun work to find quantum-proof encryption algorithms. Dr. Simmons said researchers have been working for decades to find post-quantum encryption algorithms.[92] Dr. Blais added that the National Research Council (NRC) could

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85 INDU, *Evidence*, 1 April 2022, 1325 (Simmons), INDU, *Evidence*, 5 April 2022, 1530 (Brassard).

86 INDU, *Evidence*, 5 April 2022, 1610 (Brassard).

87 INDU, *Evidence*, 29 March 2022, 1630 (Laflamme), INDU, *Evidence*, 29 March 2022, 1650 (Yazdi).

88 INDU, *Evidence*, 1 April 2022, 1335, 1410 (Simmons).

89 Ibid., 1340, 1450.

90 INDU, *Evidence*, 5 April 2022, 1610 (Brassard).

91 INDU, *Evidence*, 1 April 2022, 1340 (Simmons).

92 Ibid., 1325.

take part in this work.[93] The Canadian Security Intelligence Service (CSIS), the Communications Security Establishment (CSE) and the National Institute of Standards and Technology (NIST) are already working on developing new encryptions. NIST is expected to announce its recommendation shortly.[94] Dr. Laflamme said that algorithms in Canada are usually based on NIST standards. Canadian companies are probably waiting for this announcement to implement new encryptions.[95] Dr. Brassard said the situation is urgent even though NIST has not yet given its recommendation.[96] Intense development is needed to build a post-quantum algorithm because the cost of failure is too high.[97]

Experts are uncertain whether new encryption algorithms will hold up against quantum computing. There is no guarantee that the new codes developed by researchers or by NIST will be fail-safe.[98] Given the uncertainty surrounding the development of quantum-proof encryption, witnesses suggested that Canada should adopt multiple layers of protection. Dr. Simmons recommended:

> In addition to RSA, we can layer on all post-quantum encryption contenders that are standardized in software so that adversarial organizations must break all of them to get through. This will buy us time. For critical infrastructure, I suggest we additionally layer in provably secure defences during this encryption transition, for insurance purposes.[99]

This would protect the data now so that it can't be stored by other countries that are waiting to decrypt it when a quantum computer comes around.[100] Dr. Simmons added that an organization doesn't need to have quantum expertise to start putting in place multiple layers of protection and find the places where encryption systems have weaknesses.[101] Given the seriousness of the situation, witnesses said that Canada urgently needs to decide how to protect its systems.[102]

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93 INDU, *Evidence*, 25 March 2022, 1500 (Blais).

94I NDU, *Evidence*, 29 March 2022, 1630 (Laflamme).

95 Ibid., 1725.

96 INDU, *Evidence*, 5 April 2022, 1655 (Brassard).

97 INDU, *Evidence*, 1 April 2022, 1325 (Simmons).

98 INDU, *Evidence*, 1 April 2022, 1325 (Simmons), INDU, *Evidence*, 5 April 2022, 1655 (Brassard).

99 INDU, *Evidence*, 1 April 2022, 1325 (Simmons), INDU, *Evidence*, 5 April 2022, 1655 (Brassard).

100 INDU, *Evidence*, 1 April 2022, 1450 (Simmons), INDU, *Evidence*, 5 April 2022, 1530, 1655 (Brassard).

101 INDU, *Evidence*, 1 April 2022, 1340 (Simmons).

102 INDU, *Evidence*, 1 April 2022, 1325 (Simmons), INDU, *Evidence*, 5 April 2022, 1635, 1655 (Brassard).

On the government's part, Dr. Vats said:

> when it comes to cybersecurity, and quantum is part of that, there was a program launched last year, called the cybersecurity innovation network, that is basically to fund collaborations between universities and industry as well as training programs across the country. Colleges, to some extent, are involved in that as well, I believe. It's to make sure that the research that's being done at universities and the training that's being done at universities actually target the needs of Canadian industry when it comes to cybersecurity.
>
> That's a complement. That's more focused on cybersecurity specifically, but that's a complement to what we're doing here through the strategy. Cybersecurity and quantum are quite strongly linked in some ways. That is an important piece of the puzzle.[103]

Longer-Term Risks

Quantum cryptography has the potential to protect encryption systems from quantum computer threats. For example, quantum key distribution (QKD) is one of the most developed quantum communication techniques for securing communications. This technique generates private encryption keys to ensure the confidentiality of information exchanged between two parties.[104] However, it requires a larger infrastructure, for example, satellites in Canada because of its geography, and serious investment to be fully developed. It therefore isn't ready to be deployed right away to start securing communications quickly.[105] The Canadian Space Agency's QEYSSat mission is working to demonstrate the use of QKD from space.[106] Various quantum cryptography systems can also be used in conjunction with conventional cryptography to secure systems.[107]

The quantum Internet is also in full development. Dr. Brassard said that a "quantum Internet would connect all countries, even the whole Earth, to be linked by a quantum network in the same way as the Internet today. If we're going to be able to do that, it's going to take a lot of resources."[108] President and Vice-Chancellor Edward McCauley said that Canada is building the next generation of the quantum Internet and can play a very important role in developing this technology.[109] Dr. Brassard added that "Canada should

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103 INDU, *Evidence*, 25 March 2022, 1400 (Vats).

104 Government of Canada, *Quantum Encryption and Science Satellite (QEYSSat)*.

105 INDU, *Evidence*, 1 April 2022, 1455 (Simmons).

106 INDU, *Evidence*, 25 March 2022,1410 (Lütkenhaus).

107 INDU, *Evidence*, 5 April 2022, 1625 (Brassard).

108 INDU, *Evidence*, 5 April 2022, 1620 (Brassard).

109 INDU, *Evidence*, 1 April 2022, 1310, 1430 (McCauley).

get back the lead on this topic to secure communications, because our society needs it."[110] Dr. Simmons said that the satellites currently being developed for the QKD will also be useful for building the quantum Internet.[111] She thinks the federal government could take a leadership role in developing this infrastructure.[112] The PRC has already developed a quantum cryptography network to secure communications between Beijing and Shanghai.[113]

The Global Context

In response to questions, witnesses commented on the level of quantum computer development in North Korea, Russia and the PRC. Dr. Laflamme said that it was difficult to know what other countries were doing at this level. He said that, based on academic research, it would be surprising if North Korea developed a quantum computer soon as it does not seem to have the expertise or the technology. He added that Russia has strong expertise, but it started its work later than Canada and its partners. He said Canada's biggest competitor is the PRC.[114] Alireza Yazdi, from Anyon Systems Inc., added that the PRC did not have a quantum computer five or six years ago, but now has a 65-qubit chip bigger than Google's.[115] However, Dr. Simmons said we have no knowledge about what's happening in clandestine environments in other countries.[116]

Witnesses commented on how the Department of National Defence is managing the risks of quantum computers. Dr. Vats stated:

> the programs we [the federal government] have launched under the national quantum strategy actually enable collaboration with the Department of Defence so that we can leverage what they are doing and more strongly connect what they are doing with the academic research community and with industry to make sure that as our defence establishment is looking to develop needed quantum technologies in Canada, they are better linked to the research community and to companies so that you can be pulling those technologies to market.[117]

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110 INDU, *Evidence*, 5 April 2022, 1530 (Brassard).

111 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

112 INDU, *Evidence*, 1 April 2022, 1425 (Simmons).

113 INDU, *Evidence*, 5 April 2022, 1530 (Brassard).

114 INDU, *Evidence*, 29 March 2022, 1650 (Laflamme).

115 INDU, *Evidence*, 29 March 2022, 1655 (Yazdi).

116 INDU, *Evidence*, 1 April 2022, 1335 (Simmons).

117 INDU, *Evidence*, 25 March 2022, 1330 (Vats).

Dr. Yazdi said Anyon Systems delivered a quantum computer to the Department of National Defence in 2021, but could not comment further.[118] He added that, although a quantum computer that can break encryption is a few years away, it could have other uses for that department.[119] Dr. Brassard thinks this department should use quantum cryptography to protect its systems.[120]

Witnesses discussed the importance of international collaboration to address the risks posed by quantum computing. Dr. Brassard noted that the United States is already working to develop quantum cryptography, as are Europe and Japan. Canada, he said, needs only to choose the country or region with which it wants to work with.[121] Professor Shohini Ghose said that the race to protect past and future online data is not a race among countries because either all countries lose or all countries win, given that many organizations operate both within and outside their borders. For example, Canadian banks have transactions outside of Canada. She said that any security system is only as strong as its weakest link.[122] Dr. Vats noted that, while researchers are currently working together on security issues, there is no such strategic collaboration between countries.[123]

Witnesses also discussed the importance of managing intellectual property (IP). Dr. Vats said that universities and companies have different models for managing IP.[124] He added that the goal of the federal government is to respect business decisions while trying to keep IP in Canada, especially in areas where the federal government is investing.[125] Marie-Pierre Ippersiel, from PRIMA Québec, agreed on the importance of making sure that IP developed here is patented in Canada and stays here.[126]

Witnesses said it was particularly important to protect IP developed in Canada because of the risk of corporate espionage. Mr. Janik and Dr. Laflamme said that the commercialization of quantum technologies complicates the situation, as many

118 INDU, *Evidence*, 29 March 2022, 1545 (Yazdi).

119 INDU, *Evidence*, 29 March 2022, 1650 (Yazdi).

120 INDU, *Evidence*, 5 April 2022, 1655 (Brassard).

121 INDU, *Evidence*, 5 April 2022, 1720 (Brassard).

122 INDU, *Evidence*, 5 April 2022, 1625 (Ghose).

123 INDU, *Evidence*, 25 March 2022, 1305 (Vats).

124 INDU, *Evidence*, 25 March 2022, 1355 (Vats).

125 Ibid.

126 INDU, *Evidence*, 5 April 2022, 1730 (Ippersiel).

stakeholders want to know what is being done in Canada.[127] Dr. Simmons explained that researchers can easily obtain international contracts with funding way beyond Canadian standards. These contracts purchase the resulting IP and often insist upon secrecy as a precondition for funding. To counter this practice and corporate espionage, universities must be required to publicly disclose their international research contracts involving national security.[128] She added that there is a need for stronger CSE and CSIS support for all quantum technology companies to counter corporate espionage and strengthen cybersecurity infrastructure.[129]

Finally, witnesses noted that quantum computing will bring many more long-term positives than negatives but to benefit from it, Canada, like its allies, must be prepared to deal with the risks it poses.[130] Dr. Simmons said: “There’s going to be so much good that comes from this technology, but I don't want the public’s first impression of quantum computers to be, ‘Oh my goodness, they broke the Internet.’”[131]

MANY POSSIBILITIES

Quantum Sensors

One of the near-term uses offered by quantum technologies are quantum sensors. Witnesses explained that this technology is currently at a more advanced stage of development than quantum computers. It will be very useful since sensors are everywhere.[132] Quantum sensors measure the properties of their environment faster and more efficiently than current sensors.[133] Dr. Hall added that more discussion of quantum sensing would likely pique people’s curiosity and increase their interest in learning more about quantum science.[134]

Sensors will be useful in many industries. For example, they could provide better data in the medical imaging field with much smaller structures than current equipment.

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127 INDU, *Evidence*, 29 March 2022, 1615 (Laflamme), INDU, *Evidence*, 29 March 2022, 1625 (Janik).

128 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

129 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

130 INDU, *Evidence*, 5 April 2022, 1610 (Brassard).

131 INDU, *Evidence*, 1 April 2022, 1425 (Simmons).

132 INDU, *Evidence*, 25 March 2022, 1430 (Blais), INDU, *Evidence*, 25 March 2022, 1410 (Lütkenhaus).

133 INDU, *Evidence*, 25 March 2022, 1430 (Blais).

134 INDU, *Evidence*, 5 April 2022, 1710 (Hall).

Companies are already working on this.[135] Sensors could also be useful in the mining sector. SB Quantum, a company based in Sherbrooke, is currently developing quantum sensors for the mining industry. These sensors could be placed on drones to detect variations in the magnetic field that indicate the presence of deposits.[136]

Building Manufacturing Capacity

Building quantum computers requires many advanced materials. For example, quantum computers will not necessarily use the same semiconductors as those used to build classical computers.[137] Dr. St-Jean pointed out that, given the infrastructure required, it is very difficult for companies to build a quantum computer, and it must be done in a specialized environment.[138]

Witnesses expressed concern over the lack of domestic manufacturing capacity for advanced materials and discussed the impact of this on their company. Ms. Schwartz said that there is no domestic supply chain for some materials and no commercial-sized superconducting chip fabrication plant in Canada. Her company, D-Wave, has to use one in the U.S.[139] Dr. Blais said that, since critical materials are scarce, he is looking for an alternative approach to avoid having to use them to develop quantum technologies.[140] Dr. Yazdi claimed that “supply chain is what keeps me awake at night, and I mean it in a literal manner. These days, our [chips] are 52 weeks back-ordered, so this is very serious”.[141] He added that Anyon Systems began building all the major parts of a superconducting quantum computer in 2016 because of supply chain issues.[142] He said that this has enabled it to be largely independent from foreign suppliers and to provide domestic capabilities.[143]

135 INDU, *Evidence*, 25 March 2022, 1430 (Blais), INDU, *Evidence*, 5 April 2022, 1545 (Hall).

136 INDU, *Evidence*, 25 March 2022, 1430 (Blais).

137 INDU, *Evidence*, 25 March 2022, 1435 (Lütkenhaus).

138 INDU, *Evidence*, 29 March 2022, 1605 (St-Jean).

139 INDU, *Evidence*, 1 April 2022, 1440 (Schwartz).

140 INDU, *Evidence*, 25 March 2022, 1500 (Blais).

141 INDU, *Evidence*, 29 March 2022, 1635 (Yazdi).

142 INDU, *Evidence*, 29 March 2022, 1635 (Yazdi).

143 INDU, *Evidence*, 29 March 2022, 1545 (Yazdi).

Dr. Yazdi and Dr. Simmons also said that there are geopolitical issues associated with the lack of capacity to build advanced materials. Dr. Yazdi said that the lack of capacity to build electronics is a point of weakness for Canada and other countries. He said:

> … the whole world is dependent on Taiwan, to a great extent, especially the foundries at TSMC. I believe it is a geopolitical Achilles heel, because if China decides to invade Taiwan tomorrow, this could melt down a lot of economic sectors across the world. This is also something we should really think about in a bigger strategic and economic context than just quantum.[144]

Some stakeholders could exploit this supply chain vulnerability to terminate and obviate Canada's efforts to develop quantum technologies.[145] To address this issue, he proposed looking to the United States and choosing what priority technologies to invest to secure production in Canada. He said that Canada needs to take the supply chain very seriously, as the COVID-19 pandemic showed that Canada could not even rely on its allies for supply.[146]

> **"Canada needs to take the supply chain very seriously, as the COVID-19 pandemic showed that Canada could not even rely on its allies for supply."**

Witnesses discussed the importance of developing advanced materials manufacturing capacity in Canada. Geneviève Tanguay, NRC, said that NRC has facilities to manufacture semiconductors and quantum artifacts such as quantum dot lasers, quantum sensors and quantum repeaters.[147] However, she noted that NRC hopes to attract foreign investment to support its efforts in compound semiconductor production.[148] Dr. Yazdi also believed that Canada's manufacturing capacity at this level should be strengthened and that all companies in Canada should have access to manufacturing capacity, especially those wanting to work in quantum. He said Canada could become a world leader in this field.[149] IBM Canada added that developing a manufacturing capability for

144 INDU, *Evidence*, 29 March 2022, 1635 (Yazdi).

145 INDU, *Evidence*, 29 March 2022, 1635 (Yazdi), INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

146 INDU, *Evidence*, 29 March 2022, 1635 (Yazdi).

147 INDU, *Evidence*, 25 March 2022, 1325 (Geneviève Tanguay, National Research Council Canada).

148 Ibid., 1330.

149 INDU, *Evidence*, 29 March 2022, 1610 (Yazdi).

advanced materials would help secure important materials in the supply chain and strengthen Canada's leadership position in quantum technology.[150]

Dr. Yazdi discussed the impact of the fall of Nortel in the early 2000s. He said that this caused Canada to lose its commercial semiconductor manufacturing capacity. He added that the former Nortel workforce is close to retiring and that he would like to leverage their expertise, before they leave the workforce, to build a global industrial nanofabrication facility for quantum and semiconductor technologies. He added that he would like government to help to make this happen.[151]

Quantum technologies may also be useful for discovering and developing new materials.[152] Ms. Ippersiel said:

> quantum is seen as an enabling force and driver in the discovery and development of new materials, processes that integrate materials, or in the development of equipment for their production or characterization. Simply put, quantum accelerates simulations and will allow us to combine all kinds of properties and functionality that we want to obtain, and do it more quickly.[153]

Quantum computing will therefore be able to vastly accelerate the development of new materials, which will be a major advantage according to Ms. Ippersiel.[154]

Economic Benefits

Several witnesses agreed that quantum technologies could contribute to Canada's prosperity in the short and long term if Canada puts the right tools in place to make it happen.[155] For example, IBM Canada stated that, according to NRC data, by 2030, Canada's quantum technology industry could be worth $8.2 billion and employ

150 IBM Canada, *Brief*.

151 INDU, *Evidence*, 29 March 2022, 1610 (Yazdi).

152 INDU, *Evidence*, 25 March 2022, 1500 (Blais), INDU, *Evidence*, 5 April 2022, 1600 (Ippersiel).

153 INDU, *Evidence*, 5 April 2022, 1600 (Ippersiel).

154 INDU, *Evidence*, 5 April 2022, 1615 (Ippersiel).

155 INDU, *Evidence*, 1 April 2022, 1310 (McCauley), INDU, *Evidence*, 1 April 2022, 1315 (Fursman), INDU, *Evidence*, 5 April 2022, 1530 (Brassard).

16,000 people.[156] Table 2 shows the NRC data in more detail. Dr. Broadbent presented similar data from the research firm Gartner.[157]

Table 2—National Research Council Canada Projections on the Economic Impact of the Quantum Technology Industry in Canada

Year	Annual Revenues ($ billions)	Jobs	Taxable Returns ($ billions)	Size Compared to Gross Domestic Product (%)
2030	8.2	16,000	3.5	0.2
2040	142.4	229,000	55.0	3.4

Source: Table prepared by the Library of Parliament using data obtained from National Research Council Canada, *Economic impact of quantum technologies*, and IBM Canada, *Brief*.

Dr. Simmons cautioned, however, that the economic benefits of quantum technologies will not be evenly distributed around the world. She noted that Canada is "the country of the Avro Arrow, the CANDU reactor, Nortel, BlackBerry and Bombardier. We are the home of the first transistor patent, filed first in Canada 20 years before the first Bell Labs demonstration, and where is that?"[158] She said many quantum technologies were invented in Canada, and these examples are cautionary tales: Canada should "break through this pattern of inventing but not reaping the rewards."[159] Dr. Laflamme agreed with Dr. Simmons and stated that "quantum information science and technology is an incredible opportunity for Canada, and let's capitalize on it."[160]

BUILDING ECOSYSTEMS

Programs

Government witnesses discussed existing federal programs to support the quantum industry. Dr. Tanguay said that the NRC offers cross-sector programs to address government priorities over the next seven years of the NQS.[161] For example, it launched the new Applied Quantum Computing Challenge program and the Internet of Things:

156 IBM Canada, *Brief*.

157 INDU, *Evidence*, 1 April 2022, 1305 (Broadbent).

158 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

159 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

160 INDU, *Evidence*, 25 March 2022, 1540 (Laflamme).

161 INDU, *Evidence*, 29 March 2022, 1310 (Tanguay).

Quantum Sensors Challenge program.[162] Dr. Vats added that the federal government has several programs that can support both a company in its early stages, such as the NRC Industrial Research Assistance Program, or a company that is more advanced in its development, such as the Strategic Innovation Fund. He said that pieces already exist in Canada to support the quantum industry and that the NQS will help tie these various pieces together in an efficient way.[163]

Witnesses made various comments about federal programs to support the quantum industry in Canada. Dr. Hall said that the NRC challenge programs were quite good.[164] Dr. Simmons agreed but said that NRC is severely underfunded.[165] Witnesses said that the constraints of existing government programs can sometimes create major delays between project application and approval. The delays are so excessive that a project may have lost relevance by the time funding is approved.[166] Dr. Hall added that competitions for funding need to be more broadly based.[167] For example, programs should be open to individuals and small teams, not just researchers affiliated with large centres of expertise.[168] Witnesses were grateful that the quantum industry is receiving more targeted funding through the NQS.[169] However, Mr. Gagnon-Gordillo said the federal government needs to do more to support the industry.[170]

Witnesses had more specific comments about some programs:

- Mr. Fursman and Dr. Simmons both said the Scientific Research and Experimental Development program is very helpful at the early stages of setting up a business. It's very easy to access.[171] Dr. Simmons added that

162 Ibid., See also: National Research Council Canada, *Applied Quantum Computing Challenge program*; National Research Council Canada, *Internet of Things: Quantum Sensors Challenge program*.

163 INDU, *Evidence*, 29 March 2022, 1350 (Vats).

164 INDU, *Evidence*, 5 April 2022, 1545 (Hall).

165 INDU, *Evidence*, 1 April 2022, 1425 (Simmons).

166 INDU, *Evidence*, 29 March 2022, 1550 (St-Jean), INDU, *Evidence*, 1 April 2022, 1400 (Simmons).

167 INDU, *Evidence*, 5 April 2022, 1545 (Hall).

168 INDU, *Evidence*, 5 April 2022, 1725 (Hall).

169 INDU, *Evidence*, 25 March 2022, 1425 (Barry C. Sanders, As an individual), INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo).

170 INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo).

171 INDU, *Evidence*, 1 April 2022, 1355 (Fursman), INDU, *Evidence*, 1 April 2022, 1400 (Simmons).

she would like to see the program have a quantum-specific component;[172]

- Dr. Simmons proposed establishing a strategic innovation fund specifically for the quantum industry. The fund would accept applications from all quantum companies, including pre-revenue companies;[173]

- Witnesses liked the Deep Tech Venture Fund at the Business Development Bank of Canada. However, Dr. Yazdi found it unfortunate that the budget is pre-allocated to investing in quantum hardware companies, closing the door to start-ups.[174] Dr. St-Jean also pointed out that the fund has a horizon of 10 years, whereas quantum technologies are developed over a longer term.[175]

Witnesses also suggested ways in which the federal government could specifically support the development of quantum computers. For example, witnesses suggested that the Government of Canada act as a first user of quantum computers developed in Canada or as an intermediary to find users. This would help develop these technologies.[176] Dr. Schwartz said that Australia and Japan are already doing this.[177] If the federal government bought quantum computers, students could train on them.[178] These procurement contracts would enable companies to pay students more and further develop their quantum computers.[179] Dr. Simmons added that Canada needs to have a full-time quantum team so it can procure these computers and use them. Otherwise, Canadian companies will slip away to other jurisdictions that procure from domestic bidders, including France, Germany, the United States and the United Kingdom.[180]

Witnesses also discussed the importance of building quantum expertise within government. Dr. St-Jean said that quantum programs should be run by a team of

172 INDU, *Evidence*, 1 April 2022, 1435 (Simmons).

173 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

174 INDU, *Evidence*, 29 March 2022, 1625 (Yazdi).

175 INDU, *Evidence*, 29 March 2022, 1640 (St-Jean).

176 INDU, *Evidence*, 29 March 2022, 1550 (St-Jean), INDU, *Evidence*, 1 April 2022, 1440 (Schwartz).

177 INDU, *Evidence*, 1 April 2022, 1440 (Schwartz).

178 INDU, *Evidence*, 1 April 2022, 1345 (Simmons), INDU, *Evidence*, 5 April 2022, 1635 (Gagnon-Gordillo), IBM Canada, *Brief*.

179 INDU, *Evidence*, 1 April 2022, 1345 (Simmons).1

180 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

specialists who already have expertise and are able to quickly assess the files and ensure that the money goes to the right place.[181] Dr. Simmons said there should be a group of experts assigned only to this file within the government to preserve their independence. Germany, Australia, the United States, France and the United Kingdom already have such teams.[182] This team of experts should also ensure that the government takes a more holistic approach to its programs, from science to commercialization.[183] Dr. Ghose added that this team should also include experts with diverse backgrounds and expertise from the industries that will be affected by quantum technologies.[184]

D-Wave proposed the creation of two new programs. Ms. Schwartz proposed that the federal government create a program to facilitate access to cloud-based quantum computing. She noted that the United States is already working on this to expand access to quantum hardware.[185] She also proposed creating a sandbox program.[186] In its brief, D-Wave said that there is a need for broad education to showcase the capabilities of today's quantum systems. Creating a quantum sandbox would support rapid quantum hybrid application development and train talent. For example, the federal government could use the sandbox to focus on public sector use cases, such as CO2 emissions reduction and transportation management. Several countries, including Australia, the United States and Japan, already have similar programs in place. According to D-Wave, creating such a program would showcase Canadian innovation and speed up adoption and commercialization.[187]

Witnesses also discussed programs other countries have put in place to support the quantum industry. Dr. Laflamme said that there is a program created by the Defense Advanced Research Projects Agency (DARPA) in the United States, that link the work of researchers and companies, and he expressed disappointment that Canada does not have something similar.[188] Dr. Blais said that it would be good for Canada to have such a program.[189] Dr. Laflamme said he had heard that the mandate letter of the Minister of

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181 INDU, *Evidence*, 29 March 2022, 1640 (St-Jean).

182 INDU, *Evidence*, 1 April 2022, 1435 (Simmons).

183 INDU, *Evidence*, 29 March 2022, 1600 (Laflamme).

184 INDU, *Evidence*, 5 April 2022, 1630 (Ghose).

185 INDU, *Evidence*, 1 April 2022, 1320 (Schwartz), D-Wave, *Brief*.

186 A sandbox is an isolated testing environment that enables users to run programs without affecting the application.

187 INDU, *Evidence*, 1 April 2022, 1430, 1445 (Schwartz), D-Wave, *Brief*.

188 INDU, *Evidence*, 29 March 2022, 1620 (Laflamme).

189 INDU, *Evidence*, 1 April 2022, 1430 (McCauley).

Innovation, Science and Economic Development would float the idea of adopting such a model.[190] He added that Canadian researchers can apply to the program in the United States and therefore suggested that the federal government match that kind of model. This would speed up the process on the Canadian side because the applicants would have already been approved by a serious agency (DARPA). It would also help small companies because they face high costs having to submit multiple applications for funding.[191]

Talent Management

Witnesses discussed the importance of supporting the development of quantum talent in Canada. Several witnesses emphasized the importance of Canadian talent to support a strong and competitive quantum sector.[192] Dr. Simmons said that "this competition will be won or lost through the talent we attract and retain."[193] Dr. Vats said Canadian talent is recognized and sought after all over the world. He added that focusing on talent will help leverage quantum's potential for commercialization and provide direct benefits to Canadians.[194] Witnesses agreed and emphasized the importance for the NQS to put measures in place to attract and train the workforce at all levels in Canada to meet the needs of research centres and companies.[195]

Developing

It is important to support and develop diverse expertise in quantum and related fields. Dr. Broadbent said there is a lack of professors who foster environments for advanced research.[196] Moreover, since many technologies are involved in developing a quantum computer, students are often hired by companies whose expertise doesn't match the company's work, putting the burden of training on the company. Technical training

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190 INDU, *Evidence*, 29 March 2022, 1620 (Laflamme). After the Committee concluded its study, the Government of Canada released its Budget 2022. This budget proposes a Canada Growth Fund instead of a similar program to the one proposed in the U.S.

191 INDU, *Evidence*, 29 March 2022, 1640 (St-Jean).

192 INDU, *Evidence*, 25 March 2022, 1405 (Blais), INDU, *Evidence*, 1 April 2022, 1310, 1350 (McCauley), INDU, *Evidence*, 5 April 2022, 1600 (Gagnon-Gordillo).

193 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

194 INDU, *Evidence*, 25 March 2022, 1350 (Vats).

195 INDU, *Evidence*, 25 March 2022, 1405 (Blais), INDU, *Evidence*, 25 March 2022, 1415, 1455 (Lütkenhaus), INDU, *Evidence*, 29 March 2022, 1625 (Yazdi), INDU, *Evidence*, 5 April 2022, 1600 (Gagnon-Gordillo), INDU, *Evidence*, 5 April 2022, 1535 (Ghose), IBM Canada, *Brief*.

196 INDU, *Evidence*, 1 April 2022, 1305 (Broadbent).

should be a critical component of the NQS.[197] Witnesses added that a PhD in physics isn't needed to have a career in quantum tech.[198] The industry affects so many areas that it needs experts in other fields, such as cryogenics, engineering and business.[199] Dr. Ghose said that this interdisciplinary expertise is critical because there is no telling which technology will succeed.[200] There will also be a need to train people who do not work in quantum but who are able to use the new applications that are developed.[201]

Witnesses discussed different ideas for improving training for the quantum industry. Universities could offer more quantum and cryptography programs.[202] Dr. Broadbent said there should be more programs, internships and opportunities to link students with future careers in quantum.[203] There is a lot of funding for undergraduate students, but more funding is needed for graduate students, both from here and from around the world.[204] Dr. McCauley said that the University of Calgary is currently developing the first master's degree in quantum computing and plans to admit students in September 2023.[205]

Canada could create a national quantum training program.[206] Dr. Hall suggested that courses in this program could be rotated among different institutions across the country, which would break up competition in the academic space.[207] This coordination would benefit everyone and foster diversity and inclusion in quantum science as students from

> **"[T]his competition will be won or lost through the talent we attract and retain."**

197 INDU, *Evidence*, 25 March 2022, 1455 (Lütkenhaus), INDU, *Evidence*, 29 March 2022, 1715 (Janik), INDU, *Evidence*, 29 March 2022, Yazdi (1640), INDU, *Evidence*, 1 April 2022, 1335 (Schwartz), INDU, *Evidence*, 1 April 2022, 1455 (Simmons).

198 INDU, *Evidence*, 5 April 2022, 1535 (Ghose), INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo).

199 INDU, *Evidence*, 25 March 2022, 1450 (Blais), INDU, *Evidence*, 1 April 2022, 1320 (Schwartz), INDU, *Evidence*, 25 March 2022, 1450 (Lütkenhaus), D-Wave, *Brief*.

200 INDU, *Evidence*, 5 April 2022, 1535 (Ghose).

201 INDU, *Evidence*, 25 March 2022, 1455 (Lütkenhaus).

202 INDU, *Evidence*, 1 April 2022, 1410 (Broadbent), INDU, *Evidence*, 1 April 2022, 1410 (McCauley).

203 INDU, *Evidence*, 1 April 2022, 1410 (Broadbent).

204 INDU, *Evidence*, 1 April 2022, 1350 (McCauley).

205 INDU, *Evidence*, 25 March 2022, 1415 (Sanders).

206 INDU, *Evidence*, 1 April 2022, 1320 (Schwartz), INDU, *Evidence*, 5 April 2022, 1630 (Hall).

207 INDU, *Evidence*, 5 April 2022, 1630 (Hall).

across the country could enroll.[208] Such a program could provide multiple pathways to quantum careers, which would make the Canadian workforce agile and attract talent from elsewhere.[209] It could also provide training on security.[210] Finally, Dr. Hall said that official accreditation at the end of the program would be important to attract students from outside Canada.[211] According to D-Wave, this program could be implemented quickly as a pilot project with organizations that have an understanding of quantum computing, such as the Creative Destruction Lab in Toronto.[212]

The program could be multidisciplinary, open to different types of stakeholders, and offered in partnership with the quantum industry. For example, it could be open to students, government officials, and people already working in the industry.[213] By engaging with industry, the program would encourage quantum companies to provide training for their individual technologies, allowing for upskilling and re-skilling.[214]

Witnesses discussed the importance of collaboration between Canadian researchers and researchers outside of Canada. Witnesses said that there was a strong spirit of collaboration among researchers in Canada.[215] However, it is important for Canadian researchers to collaborate with international researchers because, although there is a lot of quantum talent in Canada, they make up only a small proportion of the world's talent.[216] Ms. Schwartz noted that Canada cannot be an expert in every aspect, stressing the importance of building international partnerships, especially with allies such as Australia and Europe.[217]

Talent diversity in the sciences, particularly in quantum, is also an important issue. Dr. Ghose and Dr. Broadbent said that there are few women in quantum because they face more barriers.[218] Dr. Ghose added that

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208 INDU, *Evidence*, 5 April 2022, 1720 (Hall).

209 INDU, *Evidence*, 5 April 2022, 1535 (Ghose).

210 INDU, *Evidence*, 1 April 2022, 1335 (Schwartz).

211 INDU, *Evidence*, 5 April 2022, 1630 (Hall).

212 D-Wave, *Brief*.

213 INDU, *Evidence*, 1 April 2022, 1320 (Schwartz), INDU, *Evidence*, 5 April 2022, 1630 (Hall).

214 D-Wave, *Brief*.

215 INDU, *Evidence*, 25 March 2022, 1415 (Sanders), 1310 (McCauley).

216 INDU, *Evidence*, 29 March 2022, 1615 (Laflamme).

217 INDU, *Evidence*, 1 April 2022, 1430 (Schwartz).

218 INDU, *Evidence*, 1 April 2022, 1305, 1400 (Broadbent), INDU, *Evidence*, 5 April 2022, 1640 (Ghose).

> Women, gender minorities and people of colour remain under-represented in science disciplines, particularly in physics, where one in five students is a woman. As of the last count, the number of black or indigenous women professors in physics in Canada was zero[219].

There is therefore untapped potential talent.[220] She explained, "it's just not very efficient or optimal to be only tapping into part of the whole workforce. We're losing out on ideas. We're losing out on economic progress."[221]

The census can provide an idea of how Canada is affected, as it collects data on employment in natural and applied sciences and related occupations for Canadians belonging to various groups. Tables 3 and 4 show that, in all categories combined, many more men than women are receiving employment income in these fields. Furthermore, median and average incomes are lower for people who identify as Aboriginal or as members of a visible minority than for those who do not.

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219 INDU, *Evidence*, 5 April 2022, 1535 (Ghose).

220 INDU, *Evidence*, 5 April 2022, 1535 (Ghose).

221 INDU, *Evidence*, 5 April 2022, 1640 (Ghose).

Table 3—Data Tables, 2016 Census, Natural and Applied Sciences and Related Occupations, Aboriginal Identity

	Number of Employment Income Recipients	Median Employment Income in 2015 ($)	Average Employment Income in 2015 ($)
Total	1,273,150	66,207	73,365
Aboriginal identity	25,755	58,140	64,428
Male	19,095	61,319	67,917
Female	6,655	49,333	54,471
Non-Aboriginal	1,247,395	66,371	73,533
Male	968,565	69,176	77,040
Female	278,835	57,712	61,425

Sources: Table prepared by the Library of Parliament using data obtained from Statistics Canada, "Occupation – National Occupational Classification (NOC) 2016 (691), Employment Income Statistics (3), Highest Certificate, Diploma or Degree (7), Visible Minority (15), Work Activity During the Reference Year (4), Age (4D) and Sex (3) for the Population Aged 15 Years and Over Who Worked in 2015 and Reported Employment Income in 2015, in Private Households of Canada, Provinces and Territories and Census Metropolitan Areas, 2016 Census – 25% Sample Data" and "Occupation – National Occupational Classification (NOC) 2016 (691), Employment Income Statistics (3), Highest Certificate, Diploma or Degree (7), Aboriginal Identity (9), Work Activity During the Reference Year (4), Age (4D) and Sex (3) for the Population Aged 15 Years and Over Who Worked in 2015 and Reported Employment Income in 2015, in Private Households of Canada, Provinces and Territories and Census Metropolitan Areas, 2016 Census – 25% Sample Data," Databases, accessed 8 December 2021.

Table 4—Data Tables, 2016 Census, Natural and Applied Sciences and Related Occupations, Visible Minorities

	Number of Employment Income Recipients	Median Employment Income in 2015 ($)	Average Employment Income in 2015 ($)
Total	1,273,150	66,207	73,365
Visible minority	349,945	63,843	68,835
Male	267,455	65,851	71,391
Female	82,490	57,721	60,545
Non-visible minority	923,205	67,132	75,083
Male	720,205	70,038	78,896
Female	203,000	57,426	61,553

Sources: Table prepared by the Library of Parliament using data obtained from Statistics Canada, "Occupation – National Occupational Classification (NOC) 2016 (691), Employment Income Statistics (3), Highest Certificate, Diploma or Degree (7), Visible Minority (15), Work Activity During the Reference Year (4), Age (4D) and Sex (3) for the Population Aged 15 Years and Over Who Worked in 2015 and Reported Employment Income in 2015, in Private Households of Canada, Provinces and Territories and Census Metropolitan Areas, 2016 Census – 25% Sample Data" and "Occupation – National Occupational Classification (NOC) 2016 (691), Employment Income Statistics (3), Highest Certificate, Diploma or Degree (7), Aboriginal Identity (9), Work Activity During the Reference Year (4), Age (4D) and Sex (3) for the Population Aged 15 Years and Over Who Worked in 2015 and Reported Employment Income in 2015, in Private Households of Canada, Provinces and Territories and Census Metropolitan Areas, 2016 Census – 25% Sample Data," Databases, accessed 8 December 2021.

"[I]t's much easier to hire a cook from abroad than a quantum

Witnesses reiterated the importance of building a more inclusive science sector. Dr. Ghose recognized that the Natural Sciences and Engineering Research Council insists on gender-based analysis plus in all its funding applications. However, the government needs to be more proactive, as she believes there has been no improvement in this area in the past decade.[222] There is no evidence that government programs have led to greater inclusion in the sciences, which shows the federal government needs to rethink and

222 INDU, *Evidence*, 5 April 2022, 1640 (Ghose).

reframe them in order to tap into all the potential out there.[223] Dr. Broadbent added that, to increase women's participation in science, issues such as harassment and childcare, which can be barriers to participation, need to be addressed.[224] Dr. Ghose and Dr. Broadbent added that equity, diversity and inclusion are recognized as catalysts to innovation, and Canada could benefit from further efforts in this area.[225]

In terms of language diversity, Dr. Broadbent said that bilingual services in the sciences need additional funding.[226] She believes Canada should double teaching resources for courses in both official languages.[227]

Attracting and Retaining

Several witnesses noted with concern the fact that Canada's talent is being recruited by other countries. They said that Canadian universities are doing well at attracting and developing talent.[228] The problem is that talent is leaving the country.[229] Dr. Broadbent said that there is competition around the world for quantum talent and Canada is losing talent to foreign companies that offer better salaries or more attractive opportunities.[230] If Canada wants to keep its talent, it must be able to match global salaries.[231] Dr. Simmons said that, for quantum companies in Canada to match global salaries, they must have substantial revenue, as global salaries are roughly 5 to 10 times the Canadian average.[232] Dr. Vats added that strategies are needed to bring back Canadian students who go abroad to study.[233]

Witnesses said that it is sometimes difficult to attract quantum researchers and workers to Canada because of the visa process. Dr. Yazdi said that it is difficult for companies to hire qualified employees from abroad. He said that, because of bureaucracy, it's much

223 INDU, *Evidence*, 5 April 2022, 1730 (Ghose).

224 INDU, *Evidence*, 1 April 2022, 1400 (Broadbent).

225 INDU, *Evidence*, 1 April 2022, 1305 (Broadbent), INDU, *Evidence*, 5 April 2022, 1535 (Ghose).

226 INDU, *Evidence*, 1 April 2022, 1415 (Broadbent).

227 INDU, *Evidence*, 1 April 2022, 1445 (Broadbent).

228 INDU, *Evidence*, 1 April 2022, 1440 (Fursman).

229 INDU, *Evidence*, 25 March 2022, 1405, 1435 (Blais), INDU, *Evidence*, 25 March 2022, 1455 (Sanders), INDU, *Evidence*, 1 April 2022, 1330 (Simmons), INDU, *Evidence*, 5 April 2022, 1600 (Gagnon-Gordillo).

230 INDU, *Evidence*, 1 April 2022, 1305, 1350 (Broadbent).

231 INDU, *Evidence*, 1 April 2022, 1440 (Fursman), INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

232 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

233 INDU, *Evidence*, 25 March 2022, 1340 (Vats).

easier to hire a cook from abroad than a quantum physicist.[234] Mr. Gagnon-Gordillo criticized the high rejection rate for visas in many priority markets, for example in French-speaking Africa.[235] To address this problem, witnesses suggested expediting visas to students and people who want to train and work in quantum in Canada.[236] Dr. Blais said visas would have an immediate tangible effect on the entire quantum community.[237] For his part, Mr. Janik said that Xanadu has been successful in recruiting international talent through Employment and Social Development Canada's Global Talent Stream program.[238]

Witnesses said the slow and complex immigration process prevents many people from staying in Canada after graduation. Dr. Simmons said that openness to immigration is one of Canada's strengths but the process is far too slow.[239] Dr. Yazdi and Dr. Laflamme said that students leave the country after graduation because it is too hard to stay and work.[240] Dr. Yazdi explained that students can get a two-year permit after graduation to stay in Canada, but the immigration process takes longer than two years. This wait is stressful for international students, and they prefer to go to a country where the process is less stressful or where salaries are higher.[241]

Witnesses also stressed the importance of making the process easier for researchers' families to settle with them. Dr. McCauley said that the process needs to be made easier and faster for individuals who want to stay in Canada and work in quantum but also for their families to join them.[242] Dr. Simmons said that she has heard from leading researchers who said they left Canada after their studies because it was too difficult for their family to obtain permanent residency.[243]

Witnesses proposed a variety of solutions to improve the immigration process for quantum talent. For example, the Government of Canada could revise the immigration process for students in the sciences to ensure they obtain permanent residency before

234 INDU, *Evidence*, 29 March 2022, 1625 (Yazdi).

235 INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo).

236 INDU, *Evidence*, 25 March 2022, 1500 (Blais), INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo).

237 INDU, *Evidence*, 25 March 2022, 1500 (Blais).

238 INDU, *Evidence*, 29 March 2022, 1625 (Janik).

239 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

240 INDU, *Evidence*, 29 March 2022, 1645 (Laflamme), INDU, *Evidence*, 29 March 2022, 1715 (Yazdi).

241 INDU, *Evidence*, 29 March 2022, 1715 (Yazdi).

242 INDU, *Evidence*, 1 April 2022, 1420 (McCauley).

243 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

they graduate. This would guarantee that Canada keeps the talent it spends money on.[244] According to Ms. Simmons, the government could also fast track the immigration process by working with CSE and CSIS. These agencies could help screen applicants in partnership with the quantum industry. Once vetted, candidates could be approved for immigration in under six weeks, according to her.[245] She noted that the fast-track immigration programs in the 1990s were "almost singlehandedly responsible for the Ottawa telecom boom."[246] She said Canada needs the same program for quantum.[247]

> **"[L]eading researchers [said] they left Canada after their studies because it was too difficult for their family to obtain permanent residency."**

Coordinating Efforts

Many witnesses said that building quantum ecosystems in Canada where academia and business interact is paramount. Witnesses said that ecosystems are critical to moving from research to technologies that will have a real impact.[248] These ecosystems would also help identify public sector needs.[249] Dr. Laflamme said it is important to think about quantum science as a whole. He added that "building ecosystems is important to sustain the path from quantum ideas to quantum technologies with societal impact".[250] Therefore having ecosystems is very important.[251] Dr. Broadbent said that Canada has a dynamic quantum ecosystem.[252] Dr. Laflamme said that there are already interactions between companies and universities in Canada (e.g., Anyon Systems and Waterloo; 1QBit and Sherbrooke), but these are mostly ad hoc. These interactions need to be

244 INDU, *Evidence*, 29 March 2022, 1715 (Yazdi).

245 INDU, *Evidence*, 1 April 2022, 1350 (Simmons).

246 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

247 INDU, *Evidence*, 1 April 2022, 1330 (Simmons).

248 INDU, *Evidence*, 29 March 2022, 1540 (Laflamme), INDU, *Evidence*, 5 April 2022, 1730 (Ippersiel), IBM Canada, *Brief*.

249 INDU, *Evidence*, 1 April 2022, 1415 (Schwartz).

250 INDU, *Evidence*, 29 March 2022, 1540 (Laflamme).

251 INDU, *Evidence*, 29 March 2022, 1630 (Laflamme).

252 INDU, *Evidence*, 1 April 2022, 1305 (Broadbent).

strengthened to increase Canada's chances of success.[253] Dr. Laflamme added that Canada must break down silos among quantum stakeholders to develop a true ecosystem.[254]

> **"It is important to think about quantum science as a whole, and therefore having ecosystems is very important."**

The NQS should support the development of quantum ecosystems in Canada. Rather than being a bunch of programs, the NQS should be a coordinated approach between academia, government and industry and support partnerships between the various stakeholders.[255] Funding under the NQS should support positive interaction between universities and industry.[256] For example, it could support leased access to infrastructure and laboratories and access to expertise for various companies and organizations.[257] Dr. St-Jean said that it does not make sense to fund the construction of this infrastructure over and over again; it's better to build it in strategic areas and then rent out access.[258] He added that the future success of Canada's quantum industry depends on the support of the ecosystems surrounding the centres of excellence in quantum technology.[259] Dr. Hall said that the NQS should also fund initiatives across the country, not just around centres of excellence, to build a broad and robust base of talent and expertise for the next 20 years.[260]

The NQS should also support initiatives across Canada to encourage the adoption of technology by different industries. Mr. Gagnon-Gordillo said there are many key players and interesting quantum initiatives in Canada, but more cohesion among the provinces and local ecosystems is needed. He said this would help boost Canada's impact on the

253 INDU, *Evidence*, 29 March 2022, 1540 (Laflamme).

254 INDU, *Evidence*, 29 March 2022, 1540 (Laflamme).

255 INDU, *Evidence*, 25 March 2022, 1505 (Lütkenhaus), INDU, *Evidence*, 29 March 2022, 1540, 1600 (Laflamme), INDU, *Evidence*, 1 April 2022, 1430 (McCauley), INDU, *Evidence*, 1 April 2022, 1345 (Fursman), INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo), INDU, *Evidence*, 5 April 2022, 1545 (Hall).

256 INDU, *Evidence*, 29 March 2022, 1700 (Laflamme), INDU, *Evidence*, 5 April 2022, 1545 (Hall), IBM Canada, *Brief*.

257 INDU, *Evidence*, 29 March 2022, 1550 (St-Jean).

258 INDU, *Evidence*, 29 March 2022, 1605 (St-Jean).

259 INDU, *Evidence*, 29 March 2022, 1550 (St-Jean).

260 INDU, *Evidence*, 5 April 2022, 1545 (Hall).

international scene.[261] Dr. McCauley added that, for all of Canada's regions to benefit from the growth in quantum tech, industrial sectors in those regions need applications. These applications are often best developed through local industry–university collaborations, reflecting the needs of industry.[262] Mr. Gagnon-Gordillo said that not all companies outside the field are aware of the possibilities of quantum tech, underscoring the importance of these partnerships.[263] Dr. Ghose added that it will take multidisciplinary experts to identify industry-specific needs and realistic quantum solutions.[264]

Building quantum ecosystems could help attract and retain talent in Canada. Dr. Blais said that growing the ecosystem here would help retain talent by attracting students, businesses and international investors.[265] Ecosystems will make it possible to assemble talent to move from quantum science to quantum technology. This will make Canada more attractive at the international level because students will see a multitude of opportunities. They will see that, even if they fail in developing a technology, there are other opportunities because there is a lot of investment and support.[266] They will feel that they are joining a community.[267] Professor Barry C. Sanders, Scientific Director of the Institute for Quantum Science and Technology, added that Canada cannot train talent and then think that companies will come to Canada. Both need to be developed simultaneously so that students have opportunities as soon as they graduate. He believes that there's a gap between talent development and company creation.[268]

Ecosystems would also support students who want to develop quantum companies. Dr. Blais said that professors should not be counted on to create companies, as there would be no professors left to train students. Instead, students should be encouraged to start their own companies.[269] Dr. Blais said that collaboration already exists between some companies and the academic community, as new companies are often born out of basic research.[270] He said that Sherbrooke's Quantum Institute ensures that graduate

261 INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo).

262 INDU, *Evidence*, 1 April 2022, 1310 (McCauley).

263 INDU, *Evidence*, 5 April 2022, 1605 (Gagnon-Gordillo).

264 INDU, *Evidence*, 5 April 2022, 1535 (Ghose).

265 INDU, *Evidence*, 25 March 2022, 1410 (Blais).

266 INDU, *Evidence*, 25 March 2022, 1440 (Blais).

267I NDU, *Evidence*, 29 March 2022, 1610 (Laflamme).

268 INDU, *Evidence*, 25 March 2022, 1455 (Sanders).

269 INDU, *Evidence*, 25 March 2022, 1435 (Blais).

270 INDU, *Evidence*, 25 March 2022, 1440 (Blais).

students have access to training to become young entrepreneurs and create their own start-ups.[271] Dr. Blais and Mr. Gagnon-Gordillo noted, however, that Canadian investors are more reluctant to invest in long-term projects and support new quantum companies. In their view, the NQS could support the early years of quantum start-ups.[272] Ultimately, these companies would also benefit from the ecosystem because of their proximity to infrastructure and expertise.[273]

Witnesses gave examples of already announced or established ecosystems or partnerships:

- The innovation zone in quantum sciences and technological applications in Quebec will bring together several stakeholders. Dr. Blais said that it will contribute to the growth of the quantum ecosystem in Sherbrooke and across Canada. He added that this ecosystem will help Canada retain its talent and attract even more students, companies and investors from abroad.[274] He believes this zone will encourage students to start their own businesses and encourage companies to come to the region.[275] IBM Canada also welcomed the creation of the zone and said that it will be installing a Quantum System One computer in the province, the first restricted-access quantum computer in Canada.[276]

- Calgary's Quantum City initiative is a partnership between the University of Calgary, the City of Calgary, the Indian IT company Mphasis, and the Province of Alberta to develop Alberta's quantum ecosystem. It will engage stakeholders at all levels.[277] The initiative aims to complement the work of experts across the country. Dr. Sanders said that Alberta has not had the same investment as other major quantum centres in the country, but now wants to collaborate with other experts.[278]

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271 INDU, *Evidence*, 25 March 2022, 1405 (Blais).

272 INDU, *Evidence*, 25 March 2022, 1435 (Blais), INDU, *Evidence*, 5 April 2022, 1600 (Gagnon-Gordillo).

273 INDU, *Evidence*, 29 March 2022, 1600 (Laflamme).

274 INDU, *Evidence*, 25 March 2022, 1410 (Blais).

275 INDU, *Evidence*, 25 March 2022, 1440 (Blais).

276 IBM Canada, *Brief*.

277 INDU, *Evidence*, 25 March 2022, 1415 (Sanders).

278 INDU, *Evidence*, 25 March 2022, 1415 (Sanders).

OBSERVATIONS AND RECOMMENDATIONS

The Committee is very pleased that its study on quantum computing has received strong support from various stakeholders in the quantum industry. These stakeholders emphasized the importance for the Committee to study such a complex topic that will have significant ramifications at many levels in Canada.

The Committee welcomes the announcement in the 2021 federal budget of a National Quantum Strategy.[279] Canada needs this strategy, given the short and long-term importance of its quantum industry, to coordinate investment and funding for the quantum industry. The strategy is a good step forward for Canada in the global race towards quantum computing. However, the industry's funding needs are considerable, as the technology is very complex and still developing. The Committee agrees with witnesses that, with the $360 million in funding that was announced, the Government of Canada will need to make strategic investments. The Committee therefore recommends:

Recommendation 1

That the Government of Canada, in consultation with quantum industry experts, ensure that the National Quantum Strategy provides sufficient resources, in a strategic manner, to the various quantum industry stakeholders in Canada to adequately support the development of the most promising technologies. This could be achieved, for example, by working with the National Research Council to launch more targeted quantum challenges with a funding envelope commensurate with the magnitude of the challenge.

Recommendation 2

That the government closely monitor the development of the venture capital industry in the advanced materials and quantum technologies industry and set up new government and partners-backed funds better suited to help young, innovative enterprises with strong growth potential, including those located outside major metropolitan centers, to access investment capital at the seed stage.

Recommendation 3

That the Government of Canada ensure that there is a constant supply of venture capital throughout the business financing chain, so that business' most promising projects can obtain suitable financing and that the government works in close collaboration with

279 Government of Canada, *Budget 2021*.

provinces and territories that already have strategies or a Center of Excellence, while promoting private sector participation.

During the course of the study, the Committee was struck by the extensive testimony on the risks posed by quantum computing to current cryptography. The Committee agrees with the witnesses that action is needed now. Although several experts do not think that quantum computing will be able to break current encryption systems for many years, it will take many years to build the encryption systems needed to protect all communications. Moreover, it is difficult to predict which systems will stand up to a quantum computer, so it is important to have multiple layers of protection in place while more robust systems are developed. It is therefore vital for the Government of Canada to put a strategy in place now to protect encryption systems, particularly banking systems and systems related to critical infrastructure such as power grids and military bases. The Committee therefore recommends:

Recommendation 4

That, as part of the National Quantum Strategy, the Government of Canada, in coordination with the National Research Council Canada, the Canadian Security Intelligence Service and the Communications Security Establishment, and in conjunction with stakeholders in banking, power grids, nuclear facilities, government communications, military communications and other affected industries, develop as quickly as possible a strategy to protect existing encryption systems at various levels:

- **in the short term to ensure that data is not stored by malicious groups or organizations; and**
- **in the longer term to protect systems from risks posed by quantum computing.**

Several witnesses said how difficult it is for companies and research centres developing quantum technologies to obtain the materials they need for their work. Most of these materials are not produced in Canada, and there are often significant delays in foreign supply chains. This reliance on foreign supply chains also poses geopolitical risks, as countries with the capacity to produce advanced materials could act at any time to thwart Canadian efforts by limiting access to important components. This issue affects not only advanced materials but also many products in Canada with supply chains outside of Canada.

To address these issues and support the quantum industry, Canada should further build its advanced materials manufacturing capacity. It should therefore put strategic investments in place as soon as possible to build this capacity. The Committee welcomes the government's announcement in February 2022 of a $240-million investment to "solidify Canada's role as a global leader in photonics and … bolster the development and manufacturing of semiconductors."[280] The Committee hopes that these investments will be made quickly to meet the needs of many industries, including the quantum industry. The Committee therefore recommends:

Recommendation 5

That, as part of the National Quantum Strategy, the Government of Canada put the necessary investments in place to build a robust and resilient supply chain for advanced materials and to develop commercial manufacturing capacity for these materials in Canada in order to support the continued growth of advanced technology industries. This will also be a step toward digital sovereignty in order to protect the industry from risks posed by reliance on supply chains outside Canada.

The Committee agrees with witnesses about the high value of Canadian talent for the quantum industry. Attracting and retaining quantum tech talent in Canada is critical to the sector's growth. The Committee is therefore concerned about talent-related issues that are holding back development of the sector's full potential, such as granting visas to bring in foreign workers and the immigration process for retaining students once they have graduated. Canada would benefit from taking steps to ensure that it keeps the talent it invests in. The Committee also deplores the lack of diversity in the sciences in Canada. The Committee therefore recommends:

Recommendation 6

That, as part of the National Quantum Strategy, the Government of Canada develop a coordinated approach to support the development and retention of quantum talent in Canada. This approach could include:

- **implementing initiatives to boost the participation of under-represented groups in the sciences, including racialized people, women and Indigenous people;**
- **establishing, in collaboration with universities, a national quantum training program to support the development of quantum expertise,**

280 Government of Canada, *Government of Canada announces significant investment in the Canadian semiconductor and photonics industries*.

attract international talent and foster collaboration among researchers across the country;

- **facilitating visas for individuals wishing to come to Canada to study or work in the quantum sector; and**
- **fast-tracking the immigration process, to ensure that students trained in Canada can stay and work in the quantum sector.**

Several programs have been introduced in recent years to support research in the sciences in Canada. Several researchers have used these programs to support their work in quantum in recent years, and the Committee commends these efforts. However, witnesses agreed on the need for more targeted programs to reflect the needs of the quantum industry, where technologies can evolve quickly and where some projects take more than a decade to develop. In addition, since quantum technologies represent a growing sector, it would be useful to have a program specifically dedicated to supporting the development of applications that can solve problems in different industries across the country. Finally, because quantum technologies are complex, the Government of Canada should also have a team of experts assigned to these programs to make sure that it makes the most strategic decisions. The Committee therefore recommends:

Recommendation 7

That, as part of the National Quantum Strategy, the Government of Canada establish a dedicated, independent quantum team to evaluate proposals for quantum initiatives and to acquire quantum tools to support the work of Canadian researchers and companies.

Recommendation 8

That the Government of Canada ensure that the programs put in place under the National Quantum Strategy adequately support the needs of various stakeholders in the quantum industry, including by providing more timely and substantial funding over the longer term to reflect the reality of developing quantum technologies, including quantum computing.

Recommendation 9

That, as part of the National Quantum Strategy, the Government of Canada create a sandbox program to support the development of applications that solve the problems of various industries across the country and thus speed up their commercialization.

During the study, witnesses agreed on the importance of building quantum ecosystems across the country. These ecosystems enable strategic investments and attract companies and talent to Canada while supporting the work of researchers. In quantum, companies often arise from the work of basic research. All stages of quantum technology development, from research to commercialization, must therefore be supported in a coordinated manner, and ecosystems make this possible. For example, the announcement of the innovation zone in quantum sciences and technological applications in Quebec was applauded by researchers and industry. Canada would benefit from supporting more such initiatives across the country to strengthen its leadership role in quantum technology while supporting the needs of its various regions. The Committee therefore recommends:

Recommendation 10

That the Government of Canada, in implementing its National Quantum Strategy, ensure that there is cohesion between the various initiatives and between the support offered to researchers and companies in order to build strong quantum ecosystems across the country that promote talent development, attract companies and ultimately advance Canada's goal of being a world leader in quantum.

Recommendation 11

That the Government of Canada strive to complete and release the National Quantum Strategy before 1 March 2023, and if that timeline is not met, that the Minister of Innovation, Science and Industry, alongside relevant departmental officials, should appear before the House of Commons Standing Committee on Industry and Technology for at least two hours to provide an update on the status and development of this strategy.

APPENDIX A
LIST OF WITNESSES

The following table lists the witnesses who appeared before the committee at its meetings related to this report. Transcripts of all public meetings related to this report are available on the committee's webpage for this study.

Organizations and Individuals	Date	Meeting
As an individual	2022/03/25	13
Dr. Alexandre Blais, Professor and Scientific Director Quantum Institute, Université de Sherbrooke		
Dr. Norbert Lütkenhaus, Executive Director Institute for Quantum Computing, University of Waterloo		
Dr. Barry C. Sanders, Professor and Scientific Director Institute for Quantum Science and Technology, University of Calgary		
Department of Industry	2022/03/25	13
Dr. Nipun Vats, Assistant Deputy Minister Science and Research Sector		
National Research Council of Canada	2022/03/25	13
Dr. Geneviève Tanguay, Vice-President Emerging Technologies		
Anyon Systems Inc.	2022/03/29	14
Dr. Alireza Yazdi, Chief Executive Director		
As an individual	2022/03/29	14
Dr. Raymond Laflamme, Professor of Physics Canada Research Chair in Quantum Computing, University of Waterloo		
Nord Quantique	2022/03/29	14
Dr. Philippe St-Jean, Chief Executive Officer		
Xanadu Quantum Technologies Inc.	2022/03/29	14
Rafal Janik, Head of Product		
1QB Information Technologies Inc.	2022/04/01	15
Andrew Fursman, Co-Founder and Chief Executive Officer		

Organizations and Individuals	Date	Meeting
As an individual	2022/04/01	15
Dr. Anne Broadbent, Professor and Holder of the University Research Chair in Quantum Information and Cryptography Department of Mathematics and Statistics, University of Ottawa		
Dr. Edward McCauley, President and Vice-Chancellor, University of Calgary		
D-Wave Systems Inc.	2022/04/01	15
Allison Schwartz, Vice-President Global Government Relations and Public Affairs		
Photonic Inc	2022/04/01	15
Dr. Stephanie Simmons, Founder and Chief Quantum Officer		
As an individual	2022/04/05	16
Dr. Gilles Brassard, Professor Department of Computer Science and Operations Research, Université de Montréal		
Dr. Shohini Ghose, Professor Wilfrid Laurier University		
Dr. Kimberley Hall, Professor of Physics Department of Physics and Atmospheric Science, Dalhousie University		
Canadian Association of Radiologists	2022/04/05	16
Dr. Jaron Chong, Chair Artificial Intelligence Standing Committee		
PRIMA Québec	2022/04/05	16
Marie-Pierre Ippersiel, President and Chief Executive Officer		
Québec Quantique	2022/04/05	16
Olivier Gagnon-Gordillo, Executive Director		

APPENDIX B
LIST OF BRIEFS

The following is an alphabetical list of organizations and individuals who submitted briefs to the committee related to this report. For more information, please consult the committee's webpage for this study.

D-Wave Systems Inc.

IBM Canada

REQUEST FOR GOVERNMENT RESPONSE

Pursuant to Standing Order 109, the committee requests that the government table a comprehensive response to this Report.

A copy of the relevant *Minutes of Proceedings* (Meetings Nos. 13 to 16 and 29) is tabled.

Respectfully submitted,

Joël Lightbound
Chair