Written Submission for the Pre-Budget Consultations in Advance of the 2019 Budget

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Recommendation: that the Government of Canada provide funding of a minimum $50 million over 5 years for a program specifically to establish Canada as the world leader in the *application* of quantum computing to address high-value business, public policy and fundamental research problems, both domestically and internationally-focused, that cannot be solved with existing classical computing resources.

Recommendation: that the Government of Canada encourage Canadian companies to explore and invest in quantum application development on challenging problems that will ensure Canada's competitiveness as an innovation leader using this new technology.

Recommendation: that the Government of Canada encourage and, as appropriate, seed funding to universities and research-intensive organizations in Canada in order that they may focus on developing programming and related infrastructure to facilitate the application of quantum computing to real-world problems.

Prime Minister Justin Trudeau brought significant attention to Canada's quantum computing field when he proceeded to explain the basics of the technology in response to a reporter's question in April 2016 during an event at The Perimeter Institute for Theoretical Physics. Indeed, Canada has been a leading proponent globally of quantum computing for decades through research occurring at Perimeter and the Institute for Quantum Computing, as well as other university efforts across Canada. Since 1999, D-Wave Systems Inc., based in Burnaby B.C., has also been a pioneer in the research and development of quantum computers and today is the world's leading vendor of commercial quantum computing systems. D-Wave's systems are currently being used by world-leading innovative organizations like Google, NASA and Lockheed Martin, to name a few. This technological advancement has put Canada and B.C. on the map internationally as a pioneer in commercial quantum computing.

Quantum computing represents one of the most exciting frontiers in technology today. It harnesses the remarkable properties of quantum mechanics in novel computing devices, enabling new algorithms and applications that promise to deliver unprecedented computational power to solve some of the most difficult problems facing humanity. Numerous governments and large corporations have recognized the potential and have begun to invest heavily in the field, including US$10 billion from the Chinese government[1] and €1 billion from the European Union[2]. Intel, IBM, Google and Microsoft have established their own research groups to build various types of hardware devices that demonstrate quantum capability. Recently, the U.S. House Science, Space and Technology Committee announced its intent to introduce a *National Quantum Initiative Act*[3] to position the U.S. as the global leader in quantum information science.

The conversation around the world has, for the most part, been focused on advancing theoretical models and building low-level hardware devices as proofs-of-concept. There is certainly much more to be learned and Canada should continue to strongly support our domestic institutions that lead the theoretical and scientific research fields. However, D-Wave's experience with customers has shown that industry is ready to take the technology out of the laboratories and explore the powerful potential for commercial use.

There are more than 70 published examples of early prototype applications using D-Wave's current quantum computing systems in areas as diverse as healthcare, energy, finance, manufacturing, transportation, defense and security. Problems in these fields are so complex that even the fastest supercomputers available today cannot deliver acceptable results in reasonable timeframes. Existing D-Wave systems are approaching, and sometimes surpassing, conventional computing in terms of performance or solution quality, heralding the potential for real customer application advantage on quantum computers. The next generations of D-Wave quantum computers already in development will deliver the power required to drive innovation well beyond the realm of any classical system. The advent of these machines will be a major milestone

[1] https://www.bloomberg.com/news/articles/2018-04-08/forget-the-trade-war-china-wants-to-win-the-computing-arms-race
[2] https://www.nature.com/news/europe-s-billion-euro-quantum-project-takes-shape-1.21925
[3] https://science.house.gov/sites/republicans.science.house.gov/files/documents/NationalQuantumInitiativeActOnePager.pdf

globally, and one led from within Canada. However, this cannot be achieved solely by industry, and requires creative partnerships and collaborations, including with the Government of Canada.

Other countries recognize the leadership of Canada's quantum computing capabilities and have already moved forward with initiatives to make use of D-Wave's technology for their research and commercial activities. In June, the Helmholtz Association in Germany together with TRIUMF Innovations, D-Wave and 1QBit in Canada, established[4] quantum computing and machine learning networks to collaborate on applied initiatives of mutual interest. In July, the Tokyo Institute of Technology and Tohoku University in Japan jointly announced[5] a quantum computing collaboration that will include the installation of a next-generation D-Wave computer in the fall of 2019. In addition to 50 researchers from the universities, it is expected that up to 20 companies will participate including DENSO and Kyocera.

> ***Establishing an ecosystem of practical quantum computing application development will drive innovation, draw investment, create knowledge and facilitate economic activity upon which the next generation of world-transforming software products will be built.***

The immediate prospect for Canada is to establish meaningful opportunities for academic researchers, entrepreneurs and interested industry partners to work on real problems that can be addressed by quantum computers. As an example of what can be accomplished here in Canada, the Creative Destruction Lab at the University of Toronto has attracted entrepreneurs from around the world to establish startups based on quantum machine learning[6], and its successful first year cohort has multiple promising ventures. One participant, OTI Lumionics, a Toronto-based developer of OLED displays and lighting, found novel ways of using the D-Wave computer for material design.

The primary areas of applications for quantum computing that are most likely to be addressed in the next decade are those in machine learning, discrete optimization, constraint satisfaction and material simulation. Machine learning is becoming critical to deal with the flood of unstructured real-time data available to businesses, necessitating automated methods to detect, analyze and make predictions upon it. Proof-of-concept demonstrations inspired by real-world problems have so far been conducted in finance, healthcare, biosciences, query optimization, image recognition and fault diagnosis. These examples illustrate the breadth of applications that are potentially addressable using D-Wave's quantum technology, for the benefit of current and future generations of Canadians, and indeed the global community. (Refer to Appendix A for a broader list).

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[4] https://www.newswise.com/articles/new-agreement-signed-to-establish-canada-germany-quantum-computing-and-machine-learning-networks
[5] https://r.nikkei.com/article/DGXMZO33101480Y8A710C1000000?s=3
[6] https://www.creativedestructionlab.com/streams/quantum2018/

The opportunity exists today to move this technology into wide-spread commercial domains. Intelligent, entrepreneurial, engaged and supported individuals and businesses will shape the future of this new computing resource. In the same way that Canada has established world-renowned capability at the Institute for Quantum Computing and the Vector Institute for Machine Learning, creating an Applied Quantum Computing Institute in partnership with provincial governments and industry is essential to advance the technology and build on Canada's leadership.

The institute would focus on the following key objectives:

1. Establish a platform for technology that is accessible by all participants, providing access to quantum computing resources through a cloud model and providing the necessary application interfaces, tools and libraries to support development across a wide range of applications.

2. Provide opportunities for the interchange of ideas and advancements and the creation of consortiums for specific applications of interest. Establish and further international collaborations such as the Helmholtz and Japanese working groups.

3. Fund the development of applications in specific fields of interest to industry participants. The funded projects are expected to involve developers from established corporations, SMEs with a variety of key expertise, new companies established specifically to address an area of commercial interest and from academia where new methodologies are explored.

4. Build an economic engine around employment, new companies, investment from national and international venture capital, and intellectual property.

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As with any new and unproven technology, industry will need to be encouraged to invest in the technology when the return on investment is still unknown. By sharing the initial costs of development, the risk for Canadian companies can be reduced to a level where participation is highly encouraged. The program should consider some level of matching funding for industry participation. Within the many categories of potential commercial applications for quantum computing, large corporations may be willing to invest in application development in partnership with universities and SMEs in Canada.

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Universities will remain a key element of the nascent quantum ecosystem. They will educate and nurture the highly qualified staff who will become theoretical and experimental researchers, entrepreneurial leaders and key development staff for commercial applications, ready to participate in industry with knowledge of quantum theory, systems and development tools.

Specialty quantum computing courses in Math, Physics, Electrical and Computer Engineering and Computer Science must be developed and offered across the country. Grants would enable hiring of qualified applied research chairs, teaching staff, and post-doc students in support of the new curriculum. It may also include funding of incubator and accelerator models associated with universities, such as the Creative Destruction Lab.

Summary

The potential of this new computing paradigm can be compared to the early days of digital computing when transistor-based technology was also in its infancy. It was unthinkable what impact that technology would go on to have in every aspect of our lives. The ultimate result of those inventions has been trillions of dollars of economic activity and employment for millions of people. We are now entering the quantum computing era and it will transform humanity in enormously beneficial and practical ways we cannot yet imagine.

With sufficient government support now, and in the face of accelerating international competition and investment, Canada can capitalize upon its significant first-mover advantages and secure a position as the global leader in quantum technologies. Providing access to quantum computing technology and services will allow researchers and application developers to deliver new capabilities to a diverse set of industries that are critical to the advancement of humanity. The expected outcome of a specific applied quantum computing program is to drive innovation from application research through technology commercialization, enabling expansion in key areas of the economy and potentially generating thousands of new jobs in Canada. Innovative ideas will spin off technology companies and highly skilled people into an expanding sector. Intelligent, entrepreneurial, engaged and supported individuals and businesses will shape the future with this new computing resource and ensure that Canada's innovation agenda is fulfilled.

About D-Wave Systems Inc.

D-Wave develops and delivers quantum computing systems and software and is the world's only commercial supplier of quantum computers. See www.dwavesys.com for more information.

Appendix A: Applications of Quantum Computing

This is not an exhaustive listing of all possible applications. The greatest impact of this technology may occur in fields yet to be discovered.

Healthcare	• Predicting new drugs • Classifying/categorizing features in medical diagnostic images • Detecting infection pattern anomalies for early outbreak detection • Optimizing radiotherapy treatment plans • Molecular matching
Finance	• Multi-time period trading trajectory optimization • Classifying requested transactions as fraudulent / non-fraudulent • Integrating heterogeneous data types for trading signals • Portfolio optimization
Materials Science	• Design and discovery of new materials • Understanding material structure, properties and performance • Development of environmentally friendly batteries
Public Policy	• Land use management • Traffic congestion • Weather prediction / climate change • Cybersecurity and terrorist networks
Energy	• Predicting energy usage to adapt to varying demand • Classifying seismic data for oil & gas exploration • Optimizing oil reservoir production • Utility grid optimization
Transportation	• Computer vision components in autonomous vehicles • Optimization of routes based on real-time data • Logistics routing and scheduling