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D-Wave Systems: Building a Quantum Computer

Anyone that is not shocked by quantum theory doesn't understand it.
— Niels Bohr, 1922 Nobel Prize Winner for Physics

It was late morning, Friday, June 6, 2003, when Dr. Geordie Rose, President and CEO of D-Wave Systems Inc., arrived at his office, a few blocks from Kitsilano Beach in Vancouver, Canada. Rose was in a celebratory mood. Not only was the sun shining after a long, cold winter, but the firm had finally closed a round of financing the day before in what was still considered an unusually chilly investment climate for technology-oriented ventures. The $7m round had been led by one of the most prominent venture capital (VC) firms – Draper Fisher Jurvetson. It was the first time any top-tier VC had invested in a start-up focused on building a quantum computer.

D-Wave's business model was rather unique. To this point, the firm had been coordinating the research efforts of an extensive network of scientists working at public research institutions, such as universities and national laboratories. In return for a modest level of funding, almost a dozen quantum-related research groups around the world had assigned the right of first refusal for ownership, or at least exclusive use, of their relevant intellectual property to D-Wave. The degree to which this small, unknown company with only 13 employees was orchestrating such a large-scale, international science project was unprecedented. Rose however, was now questioning this structure.

Using the "research collaboration network" had been less expensive than conducting research in-house, affording great flexibility to D-Wave, while facilitating access to leading scientists who often preferred working in a non-corporate environment. On the negative side however, it was less efficient in terms of coordinating and controlling the progress of projects, and made it difficult to maintain secrecy about the outputs of these projects. It also left D-Wave exposed to increases in the prices charged by public institutions for their quantum-related intellectual property. Rose was now considering whether to begin moving key research projects in-house. He explained:

> Our goal is to bring a quantum computer to the market within five years. A decision to move research in-house would probably take at least two years to implement. So setting up a centralized research facility now seems the right thing to do. But I'm not sure how to rationalize the decision. There are no obvious net present value calculations to use, since the pros and cons are almost impossible to quantify. Unfortunately, in the world of quantum computing, nothing is for certain.

Professors Ajay Agrawal (University of Toronto), Rebecca Henderson (MIT), and Alan MacCormack prepared this case with research assistance from Rosemary Stewart. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

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The History of Quantum Computing[1]

The history of quantum computing could be traced back to at least the turn of the 20th century and the beginnings of quantum theory. In 1900, physicist Max Planck proposed that energy was not emitted in a continuous manner as previously theorized in classical physics, but rather in discrete packets, or quanta. This hypothesis, which Albert Einstein later used to explain the photoelectric effect, became the basis for quantum theory. Although many developments arose from quantum theory over the years, the idea of using it to build a computer was relatively recent, emerging in the late 1970's, as a result of scientists pondering the fundamental limits of computing power.

All existing computers work according to a set of principles first articulated by mathematician Alan Turing in 1936 and enhanced by John von Neumann in the 1940s. These principles define a paradigm known as "classical computation." The key to improving the performance of classical computers has been the reduction in size of the transistors used in their microprocessors. However, there are physical limits to how small these transistors can be. Eventually (some think as soon as 2010) we will reach a point where the individual elements that make up a transistor are no larger than a few atoms. This presents a problem, because at such a small scale, the physical laws that govern the behavior of a circuit are no longer classical, but become quantum mechanical in nature.

In 1981, Richard Feynman raised the question of whether a new computing device could be devised to leverage the principles of quantum mechanics.[2] Feynman's motivation was the inability to create an exact simulation of a quantum system on a classical computer. Classical computers could provide an approximate simulation of such a system but lacked sufficient computing power to account for the multitude of scenarios that would exist in a quantum system. In 1982, he produced a paper showing how a quantum-based machine could be used for computations. He explained how its ability to model multiple states meant that such a machine could simulate a quantum system exactly.

In 1985, English physicist David Deutsch published "Quantum Theory, the Church-Turing Principle and the Universal Quantum Computer." Among other things, Deutsch's paper highlighted the key difference between quantum computers and their classical counterparts, namely a quantum computer's ability to perform parallel operations. This parallelism hinted at the potential computing power available with a quantum computer. In theory, *any* physical process could be modeled perfectly by such a computer. The search for interesting applications began in earnest. Unfortunately, all that could initially be found were a few rather contrived mathematical problems.

In 1994, one of the most important events in quantum computing history occurred. Peter Shor, a researcher at Bell Labs in New Jersey, set out a method for using a quantum computer to factor huge numbers extremely rapidly. The implications of this finding were most significant in code breaking. The most commonly used method for sending encrypted data was public key encryption, which relied on the impossibility of even the most powerful computers to factor very large numbers. In

[1] This brief history is based on the following references, which each provide a more complete historical account for the interested reader: Nielsen, M. and I. Chuang, Quantum Computation and Quantum Information, Cambridge University Press, 2000, pp. 2-12; Brown, J., The Quest for the Quantum Computer, Simon & Schuster, 2000, pp. 73-120; and Johnson, G., A Shortcut Through Time: The Path to the Quantum Computer, Alfred A. Knopf (publisher), 2003, pp. 24-49 and 291.

[2] The first general conference on the Physics of Computation was held in 1981 at MIT. The papers from that conference were published in the 1982 International Journal for Theoretical Physics, Vol. 21, April, June, and December issues.

theory, it would take a classical computer an estimated 10 million billion billion years to factor a 1,000 digit number, whereas a quantum computer would take only around 20 minutes.[3]

A year later, attention returned to quantum computing when another Bell Lab employee, Lov Grover, published "Quantum Mechanics Helps in Searching for a Needle in a Haystack." In this paper, Grover presented an algorithm that would later bear his name. It theorized that large database searches conducted with a quantum computer could be completed in a fraction of the time required by a classical computer. This pointed to another useful application, further increasing public and private sector interest in the goal of making a quantum computer become reality.

Building a Quantum Computer

Quantum computers differ from conventional computers in that the fundamental information storage device on a chip is generalized from being exclusively "on" (binary 1) or "off" (binary 0) to a state where both states can co-exist (i.e., can be both "on" and "off") simultaneously. A device allowing this co-existence is called a quantum bit, or qubit. The co-existence of two states in a one-qubit device leads to the key enabling property of a quantum computer. Two qubits can hold four different states simultaneously ("00," "01," "10," and "11"). Three qubits can hold eight different states simultaneously. More generally, N qubits can hold 2^N states simultaneously. It is this ability to hold many values simultaneously that makes qubits, and hence quantum computers, so useful.

Consider, for example, the difference between a 4-bit classical computer and a 4-bit quantum computer. The former can hold any one of 16 different numbers (0000 through 1111). The latter can hold all these numbers simultaneously. Assuming we wanted to find the factors of a specific 4-bit number, classical computing requires that we perform 16 different operations (i.e., dividing the specific number by each of the possible factors, 0000 through 1111, and looking at the results). But with a quantum computer, we can do the same calculation in a single operation, given that a 4-qubit device holds all possible 16 factors simultaneously. All that is required is to find a way to get the final answer to "reveal" itself in the classical world (a process called *decoherence*).

Actually building such a device was a major challenge. Despite the discovery of several theoretical algorithms that relied on the existence of quantum computers for their execution, it was not until 2001 that the first demonstration of Shor's algorithm occurred, when researchers from IBM's Alameda research center and Stanford University factored the number 15 using a 7-qubit quantum computer. This seemingly trivial calculation represented a huge accomplishment. The results were reported in the prestigious journal *Nature* as well as on the front-page of *The Wall Street Journal*.

IBM performed its 2001 demonstration by controlling the spin of nuclei in seven atoms of a synthetic molecule, using Nuclear-Magnetic Resonance technology. Subsequently however, several radically different technologies for building quantum computers began to emerge around the world. At the National Institute of Standards and Technology, scientists ran calculations by flashing pulses of laser light onto Beryllium atoms that had been chilled to near absolute zero. A California University of Technology (CalTech) experiment used light particles bouncing between two mirrors for their quantum bits. By Contrast, D-Wave's research network focused on the use of superconducting electronics. Typically, most research groups tended to focus exclusively on one of four main technologies, given the depth of knowledge needed to drive progress in each. By 2003, it still wasn't clear which of these "tracks" offered the most promise in terms of commercial viability.

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[3] The comparison between classical and quantum computers presented here is from the online text "A Brief History of Quantum Computing" by Simon Bone and Matias Castro (http://www.doc.ic.ac.uk/~nd/surprise_97/journal/vol4/spb3/).

The concepts underlying quantum computing seemed so non-intuitive that it was difficult for most lay people to envision what one would look like. A superconducting quantum computer would likely fill a 100-square foot floor space (a small room) about half of which would be for cooling systems and the other half for electronics. The chip at the heart of the system would be a 5mm-square wafer. Over time, the system would likely come down to the size of a desktop PC. (See **Exhibit 1** for a series of photographs of key parts of a superconducting quantum computer).

Applications for a Quantum Computer

By 2003, three classes of algorithms were known to use a quantum computer's increased power to solve problems that defeated classical computers: Shor's Algorithm for factoring the product of two prime numbers, which had application in cryptography/code-breaking; Grover's Algorithm for searching a database, which had applicastions in increasing the efficiency of large database searches; and the simulation of quantum systems themselves, which had application in computational biology and chemistry, including the simulation of molecules for pharmaceutical discovery and genetic engineering. Of these areas, molecular simulation was D-Wave's primary focus.

The motivation for using quantum computers for simulation was based on the observation that it was impossible to solve the fundamental equation of quantum mechanics (Schrodinger's Equation) using classical computers for systems containing more than a handful of "particles." This is because the amount of information needed to store and process doubles with every particle that makes up the system being studied, quickly growing beyond the capacity of any classical information system. In many systems of interest in chemistry and biology, the particles ultimately responsible for the behavior of the system are electrons. Predicting the properties and behavior of a molecule from first principles, that is exactly duplicating the way nature itself works with no approximations, involves solving Schrodinger's Equation for the number of electrons that the molecule contains.

As an example, predicting the properties and behavior of a caffeine molecule, which contains 102 electrons, requires solving the Schrodinger Equation for 102 electrons. This requires the storage and processing of 2^{102} classical bits of information. This number is very large, far greater than the sum total of all the information ever recorded in the history of humanity. Another way of understanding this problem is that storing 2^{102} bits with state-of-the-art storage devices would require six times the mass of the Earth in 50 gigabyte hard drives. However, this does not mean that it is impossible to solve Schrodinger's Equation for a caffeine molecule. Nature does it easily; caffeine molecules regularly solve Schrodinger's Equation in real time. All atomic and molecular level substances do this just by obeying the laws of quantum mechanics. They can be thought of as "analog computers" that are excellent at solving their own particular Schrodinger Equations.

In essence, to predict the properties and behavior of molecules, it was necessary to solve the Schrodinger Equation for the molecule in question. The only method currently available is to actually build the molecules and observe their properties in nature. The invention of quantum computers that are able to simulate the properties and behavior of molecules therefore promises to fundamentally change the way substances are designed at the molecular level.[4] Given the ability to assemble and manipulate particles at the atomic level is the basis of nanotechnology, it is clear that a quantum computer could provide a dramatic boost to this area of technological development, among others.

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[4] This had been recently confirmed by research conducted at Los Alamos National Laboratory in New Mexico. Oritz, G., J.E. Gubernatis, E. Knill, and R. Lafflamme, "Quantum Algorithms for Fermionic Simulations," *Physical Review A*, Vol. 64, 2001.

D-Wave Systems: A Small Firm with Big Plans

While the dream of building a quantum computer was both large and old, D-Wave as a company was small and young. The company was founded in 1999, and by June 2003 directly employed only 13 people. The firm was a spin-off from the physics department at the University of British Columbia (UBC) in Vancouver, Canada, where the four founders had met.

The founders included Rose, Alexandre Zagoskin, Haig Farris, and Bob Wiens. Rose, 33, was President and CEO. He held a Ph.D. in theoretical physics from UBC, specializing in quantum effects in materials. Zagoskin, 42, was VP of Research and Chief Scientist. He held a Ph.D. in solid-state physics from the Institute for Low Temperature Physics and Engineering at the Ukrainian Academy of Sciences, and had authored 53 peer-reviewed scientific articles as well as a widely used textbook on the quantum theory of many-body systems. Farris, 65, was Executive Chairman. He was also President of Fractal Capital Corp., a private venture capital company financing high technology start-ups, as well as a professor at UBC, where he ran an MBA course on the formation, financing, and management of high-tech firms (in which Rose had conceived his idea and drafted the first business plan). Wiens, 47, was Chief Financial Officer. A member of the Institute of Chartered Accountants and the American Institute of Certified Public Accountants, Wiens had previously been President and CEO of a firm listed on the Toronto Stock Exchange.

Although Rose had no management experience, Dr. Alexei Andreev, the associate at DFJ who had led the due diligence on D-Wave, thought Rose brought valuable leadership qualities to the venture:

> Geordie has no formal management training or experience. However, we talked to his prior investors and discovered that he had given them a series of milestones that he had hit without exceptions. Geordie had a reputation for delivering on his promises. We have invested in many companies run by first-time entrepreneurs, such as Hotmail, Overture, and GoTo. In general, there are many successful technology firms run by first-time entrepreneurs, such as Microsoft, Yahoo, Google, and eBay. So, that in itself is not a problem.

Andreev also explained DFJ's thinking in terms of Rose's youth:

> We recognize that Geordie is young. But Tim Draper, who founded our firm, is a big proponent of investing in young entrepreneurs who have the drive to move forward. At some point, it might be optimal to have a well-seasoned CEO come in, but at this point Geordie is an ideal fit. He's a cofounder, he wants to do it, it's the project of his life, he's proud of what he's doing, he's driven, and he wants to change the world. The DFJ logo is 'change the world' and we look for entrepreneurs who want to do just that.

Overall, Andreev considered the team, particularly Zagoskin, Rose, and Farris, in combination with the huge upside potential of their venture, the primary reason for the DFJ investment:

> Alexandre has a solid scientific reputation, he publishes a lot, and he is well respected by the scientific community in general, which we confirmed through a number of our contacts. As a result, he has access to a good scientific network. Geordie is also a scientist, but in addition he is a competitive sportsman, he is personable, and everyone who has worked with him seems proud to have worked with him. He listens to advice, knows where his weaknesses are, and doesn't have big ego problems. He is also very honest and upfront about where the problems are. Haig is a well-known VC, and he has put in his own money as well as his own effort, which tells us that he really believes there is something here. He also helped to move

this from a scientific project to something more down to earth and has served as a mentor to Geordie and Alexandre, so he brings operational and financial expertise to the team.

In addition to the positions of CEO, CFO, and VP of Research, D-Wave's other employees included a senior scientist, two researchers, a research assistant, a director of intellectual property, two patent personnel, a programmer, a system administrator, and a human resources coordinator.

D-Wave's Business Model

D-Wave's business model was to invent, design, patent, and build quantum computers. The company would not sell the machines, at least at first, but rather keep them in-house and offer very specialized computational services to companies in the life sciences, materials sciences, and more generally, nanotechnology-based industries. Indeed, the primary motivation for DFJ's investment in D-Wave was the belief that quantum computers would be an important complement to the development of nanotechnology, an area in which DFJ was the world's leading private investor. By 2003, DFJ had invested in 18 different nanotechnology ventures.

D-Wave's hardware platform was to be built using superconductor-based electronics technology developed through state-of-the-art lithographic techniques. The firm projected that its quantum computer would reach an integration level of approximately 30 qubits in Q4 2007, by which time it would be competitive to high-end supercomputers for certain computational tasks, including the simulation of quantum systems such as small molecules (see **Exhibit 2** for D-Wave's timeline).

While the firm had won the support of DFJ, many observers remained skeptical, especially about the proposed timeline. For example, *USA Today* ridiculed the investment:

> So a guy from a reputable venture capital firm calls and says the firm just funded the world's only start-up aimed at building quantum computers. Now, this is basically like saying they'd just financed the first resort on the moon. Or cloned Elvis. You know that someday these things are going to happen, but not for a very long time.[5]

Competitors also reacted coolly to DFJ's investment in D-Wave. "In terms of incremental progress… they are contributing like the rest of us,' said Tim Blair from IBM Research. 'But in terms of breakthroughs or building a computer, we have not seen anything from them."[6] Dr. Roger Koch, a physicist leading IBM's quantum computer efforts considered D-Wave's timeline unbelievable:

> No one really knows how long it's going to take to build a quantum computer that does anything actually useful. I mean, people have made 7-qubit quantum computers already, but they can only factor the number 15. My sense is that D-Wave realizes that quantum computing is a hot buzzword right now and so they can propose these plans in order to get some venture capital money. They need to show some kind of short-term timeline so they can put food on the table, so to speak. I think the thing about quantum computing is that in order to make anything useful, miracles have to occur. It's going to take a very long time.[7]

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[5] USA Today, June 25, 2003 (p. B.03).

[6] USA Today, June 24, 2003 (p. B.03).

[7] Interview with Roger Koch, January 2004.

Other research leaders tended to agree, including Dr. Ray Beausoleil, a project leader at HP, and Dr. Bob Clark, Director of the Center for Quantum Computer Technology, who coordinated research across eight labs at Australian universities and the Department of Defense. Asked when a quantum computer might match the performance of a 2003 64-bit SunFire 12K machine, both estimated sometime after 2012 and likely not before 2020, if at all. By comparison, D-Wave listed this as a milestone for Q4 2006.

D-Wave's Operations

D-Wave performed five main functions at their Vancouver location: They raised financing to fund the company's operations; conducted in-house research on the design of superconducting quantum computer components; conducted scientific surveillance to identify research initiatives world-wide that had relevance to D-Wave's technical objectives; coordinated research projects with their collaboration partners and conceptualized how the related inventions would fit together; and drafted patent applications and negotiated acquisitions or licensing agreements for inventions developed outside the firm's network. The company's burn rate averaged $3m/year from 1999-2003, including payroll for its employees, overhead costs associated with its office, payments to research groups in the network and licensing, legal and administrative costs associated with its patent portfolio.

The Research Collaboration Network

D-Wave's competitive advantage was based on its scientific lead in developing a quantum computer using a promising approach (superconducting electronics) coupled with careful protection of its intellectual property (IP). D-Wave had more patents issued and pending on this topic than any other competing firm (see **Exhibits 3 and 4**). D-Wave developed its IP portfolio from three sources: in-house research performed by theoretical physicists located in Vancouver; "outsourced" research performed by scientists in the research collaboration network who were partially funded by D-Wave; and acquired research performed by scientists who were neither employed by D-Wave nor members of its network. Of these, the collaboration network was most central to the firm's strategy.

D-Wave had signed contracts with researchers from a variety of disciplines related to the goal of building a quantum computer, including theoretical physics, experimental physics, and materials science. The scientists were all employed by public institutions, such as universities and government research labs. While D-Wave directly employed only six Ph.D. scientists at its headquarters in Vancouver, it counted 46 Ph.D.s in its research collaboration network. This represented a significant effort in terms of size; large competing firms such as IBM and HP (claimed they) each employed fewer than 10 full-time equivalent scientists working on building a quantum computer.

As incentive to join the network, D-Wave offered researchers partial funding for their research projects and access to other scientists, tools, and equipment within the network. In return, D-Wave requested ownership of (or at least exclusive rights to) the IP developed by the research group and an opportunity to file for patent protection prior to any publication of results (which could result in a publication delay of up to 90 days). The terms of the relationship between D-Wave and the research labs in the collaboration network were outlined in a formal contract. This contract was the "glue" that held together disparate research activities scattered around the world and governed the flow of IP from nodes in the network to headquarters in Vancouver (see **Appendix A** for extracts).

In addition to the formal terms of the collaboration contract, there were a few informal restrictions placed on scientists in the network. Rose offered an example:

> In the early days, we insisted that everybody publish in the journals where they used to publish before. So if we had a materials science person working on something for us, we wanted them to keep publishing in materials science journals. We didn't want them publishing in quantum computing journals because that raises a whole bunch of red flags for potential competitors. Whenever someone who is a famous person in one field switches to another, everybody talks about it in the scientific community. So we didn't want quantum computing appearing anywhere in any of their publications, and usually they were fine with that because they didn't want to do that anyway. Now we have secured the rights to a lot of the IP, so we don't have to worry so much about keeping under the radar.

By 2003, D-Wave had established a network that included research groups associated with 10 institutions: The University of British Columbia in Canada, Chalmers University of Technology in Sweden, and the Institute for Physical High Technology in Germany in 1999; the University of Sherbrooke in Canada in 2001; the University of Twente in the Netherlands, the University of Erlangen-Nurnberg in Germany, Comenius University in the Slovak Republic, the Institute for Low Temperature Physics and Engineering in Ukraine, and the University of Toronto in Canada in 2001; and the National Physical Laboratory in Great Britain in 2002.

The Benefits of the Network

While much of the leading research in many "applied" fields occurs in corporate labs, most of the research relevant to quantum computing was still considered "basic" by 2003, and was conducted at publicly funded universities and institutions (see **Exhibit 5**). The early-stage nature of this research attracted particularly creative scientists who were often more comfortable in university-type settings than in corporations. In other words, it was not certain that a corporate lab could recruit the top scientists in the field, since many placed a high value on the creative freedom afforded by a university environment. D-Wave's collaboration network enabled the firm to access some of these leading scientists, while securing the rights to key pieces of intellectual property related to the technology of superconducting electronics. It also allowed the firm to access the expensive equipment these scientists used. In November 2001, two years after founding the company and having raised only $2.5million in equity financing and $0.5million in grant funding, the total value of capital equipment being used by researchers in the D-Wave network was $440million.

The benefit for scientists working in the network came primarily from the funding they received from D-Wave, and the opportunity to interact more closely with other researchers that D-Wave had recruited. For this purpose, D-Wave held regular conferences for network participants, and often brought scientists from different projects together to share experiences and solve problems that might benefit from a variety of different perspectives. In this respect, Rose believed that D-Wave's approach to coordinating research was more efficient than the natural collaboration that would occur between scientists operating within public institutions. Dr. Colin Williams, a lead scientist in quantum computing working at CalTech's Jet Propulsion Laboratory, agreed:

> D-Wave purchased an exclusive license to use my software for designing quantum circuits. Given a high level description of a quantum computation you want to do, my software reduces it to a sequence of gate operations analogous to a logic circuit in a conventional computer. The reason D-Wave was an attractive licensee was that they already had complementary software that would take a circuit diagram and reduce it to a sequence of electrical and magnetic pulses

> that would actually operate the device. So if you put the two things together, we have something that is better than either one alone. It's an advantage working with D-Wave because they are contributing resources to developing the software further and mapping it into different computer programming languages that would make it more broadly useful. I think if I put it in the public domain it would be an interesting toy for a lot of scientists. By putting it into a company, it has an opportunity to grow into something much more substantial.

While the network's scientists seemed content with the collaboration contract, some remained opposed in principle to the idea of secrecy and, in some cases, the idea of patenting. Those opposed to secrecy felt that it was unfair to benefit from results published in the scientific community yet not contribute to this endeavor. They felt that it outside the norms of Science to not share results as soon as they were discovered. Some observers felt that the really top scientists would not participate in such a relationship since it could deprive them of the most valuable reward from their efforts – peer recognition. Scientists opposed to patenting believed that ideas and discoveries related to the mechanics of Nature should be kept in the public domain so that anyone could build on them without having to worry about permission from property-rights owners.

Managing the Network

Since D-Wave did not currently have its own research facility (its in-house research was theoretical in nature, requiring only the use of desktop computers) the entire value of the firm was predicated on its existing IP portfolio and its pipeline of incoming IP. D-Wave's investors had requested a third-party evaluation of its IP management practices, to be completed by a top tier US-based intellectual property law firm. The results suggested that the firm had done an excellent job developing policies and procedures to protect its IP portfolio (see **Appendix B** for extracts).

The mechanics of managing the transfer of IP from D-Wave's network to the firm's headquarters in Vancouver fell on the shoulders of Jeremy Hilton, D-Wave's Director of Intellectual Property. Hilton did not compare his role at D-Wave to that of someone in a research department in the private sector but indicated that it most resembled a university technology transfer officer. His job was to help identify relevant research wherever in the world it occurred, work with inventors to draft invention disclosures or patent applications, and negotiate IP transfer agreements.

Hilton also kept a close eye on developments in the field made by scientists outside the network. When such discoveries were relevant to D-Wave's technical trajectory, the company would attempt to acquire the intellectual property or at least secure exclusive rights to it. For example, D-Wave had recently secured exclusive licenses for two key inventions from publicly funded research institutions including: A particular type of qubit called the Quantronium qubit from the French government agency, Commissariat a l'Energie Atomique (CEA)[8]; and software for designing quantum circuits from CalTech's Jet Propulsion Laboratory.

By Q1 2003, D-Wave was taking a very active approach to managing the collaboration network, terminating projects that were inconsistent with its technology roadmap, and focusing resources on those that were more successful. D-Wave's research agreements gave them the right to terminate projects without cause (see **Appendix A**). These moves were an important step in demonstrating to investors and other scientific collaborators the flexibility of D-Wave's research network and the firm's commitment to seeing its technology roadmap executed successfully. It also freed up resources to

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[8] An article about the French research on Quantronium appeared in the journal *Science* in May 2002 where it was described as having more promising characteristics than any other supercomputing qubit built so far.

add new projects and IP to the portfolio. Rose explained the approach: "Focus on what works, wherever it is and whoever invented it, and don't spend a dime on anything that is not contributing to the firm's current technology roadmap and is not best-in-class."

Re-thinking the Structure of the R&D Organization

Despite the successes that D-Wave had achieved with its research collaboration network, Rose was concerned that this structure would not serve the firm's needs much longer. With a target of building a viable early-stage commercial product within five years, it was clear that at some point, D-Wave would have to ramp up its internal R&D capabilities, and bring on-board skilled engineering talent to put such a device together. But Rose thought there were also strong reasons for centralizing the research activities now being conducted by the network. As he saw it, the decision came down to three factors: the increasing cost of acquiring IP from universities; the difficulty of keeping D-Wave's IP under wraps; and the potential for increased productivity that centralization would bring.

Rose was concerned that the costs associated with the research collaboration network would increase significantly in the coming years; he had already experienced tougher negotiations with two institutions that had learned of D-Wave's financing from DFJ. Since the market for sponsored research in superconducting electronics relevant to quantum computing was thin, it was difficult to objectively determine a price for rights to the research. This left D-Wave exposed to the risk that public institutions would raise prices based on an increase in their perceived value (or their perception of D-Wave's willingness to pay). Increased interest in the rights to IP developed at these institutions might also lead to bidding wars with other firms, some of whom had deep pockets. The amount of relevant scientific research being conducted had accelerated dramatically in recent years, and now even the press was taking notice of quantum computing advances (see **Exhibits 7 and 8**).

Rose also suspected that the firm would be better able to control information flow if all D-Wave's scientists worked in a single location. He explained, "Every physicist I've ever met can't keep their mouth shut about the wonderful things they are working on. For example, just the other day I met with someone at UBC and in half an hour he explained to me all of his ideas that he's had over the past year." Rose suspected that while the company could not totally control information flow, it could at least better manage it if the majority of scientists were located under one roof, were bound by formal full-time employment contracts, and were immersed in the corporate culture at D-Wave.

Finally, Rose believed that he could increase productivity substantially if the research scientists were co-located. He had noticed that problems that had vexed different research groups for weeks were often solved quickly when teams flew together for brainstorming meetings. He explained:

> It makes a difference when scientists can work together at the bench level. It's amazing how important ideas are often developed over lunchtime conversations and seemingly intractable problems are surmounted. A small but measurable increase in productivity could be tremendously valuable. Remember there are four parallel scientific tracks in motion and we have placed our bet on the superconducting electronics approach. If this track is able to achieve enough of a lead such that the general research tools are more advanced, then more researchers will be likely to base their research on superconducting electronics. A small lead will become a big lead and superconducting electronics will become the dominant design for quantum computing. That could make the difference between our patent portfolio being worth something modest, or something huge.

The most obvious downside of bringing research in-house, relative to the current network structure, was the large costs this would incur. Rose estimated that building a facility and moving even just the key projects in-house would cost D-Wave approximately $100million. He noted:

> We were recently in discussions with a Canadian government agency that might fund a significant fraction of the money and they asked 'well, this might take a billion dollars, not 100 million, and if it takes a billion dollars, how are you going to fund it?' That's a good question. If you don't know what every line item is on the budget and there is a potentially large variance in the time to get to market, the numbers could go way up. But even if success takes a billion dollars, there is a good economic reason for doing it. The return will be much greater than the investment. If you want to look at comparables, look at other local, successful research-oriented ventures like QLT [a pharmaceutical firm], or Ballard [a fuel cell manufacturer], which have gone through a billion or more. The numbers sound frightening, but they have to be put in the context of what D-Wave is trying to achieve.

In addition to facility costs, the payroll expenditures associated with recruiting and maintaining dozens of Ph.D. scientists would far exceed the few million dollars per year the company currently paid to fund the collaboration network. Over the four years of their operation, D-Wave's funding averaged only $50k per full time equivalent (FTE) for Ph.D.-level scientists. Recruiting the people they would need, with the requisite skill sets and personal characteristics, would be a major challenge, given there was no guarantee that scientists in the network would want to come on-board. Rose had already experienced the problem first hand. He explained:

> I've been trying to recruit a VP of Engineering. I described the job specification to the recruiting firm as someone who had led a complex, science-heavy project. But I didn't specify what I meant by complex and science-heavy. So we had people from wireless companies and things like that. I said 'I don't think these people meet the requirements' and they replied 'what do you mean, it says complex and science-heavy and they worked in wireless.' So they asked me to define what I meant. I sent them a list of projects that I felt were comparables, like The Manhattan Project, the Superconducting Super Collider, which of course failed but was a billion-dollar science project, and missions to Mars. I ran off a list of about 15 of these things and you could see that they had no concept when we first engaged them that we were asking them to help us find this generation's Robert Oppenheimer. Our project might be the most difficult and ambitious engineering project ever attempted in the history of humanity, and to have any shot at all we absolutely need the best people in the world. Full stop.

Location, Location, Location

If Rose decided to bring D-Wave's research in-house, he also needed to decide where to locate it. The firm's headquarters had been in Vancouver since its founding in 1999, but Rose recognized that other locations might be better for the firm's growth. Among the options he was considering:

Vancouver, British Columbia

D-Wave had become a recognized and respected company in Vancouver. It had won the "Most Promising Start-Up" and "Most Promising Pre-Commercial Technology" awards from the British Columbia Technology Industry Association. Also, Farris was well known throughout Vancouver's business community. In addition to his roles as an adjunct professor at one of Canada's largest universities and as one of the city's most active early-stage technology investors, he was a former

Board member for the Vancouver Opera, the Vancouver Playhouse, and the Vancouver Waterfront Theatre. Similarly, Weins had chaired a number of charitable committees in the Vancouver area.

Rose, Zagoskin, and the entire scientific team who worked at the Vancouver headquarters had close ties with the physics department at UBC. All of D-Wave's investors, except DFJ, were from the Vancouver area. Finally, all of the grant funding that D-Wave had received to date was from the Canadian government, and the company was hoping to be awarded a substantial amount more in the coming years. D-Wave would only be eligible to receive such funding if it remained in Canada.

Silicon Valley, California

Both Andreev of DFJ and Williams of JPL agreed that Silicon Valley was the optimal location for D-Wave's research facility. The greatest amount of activity in quantum computing research, at least in terms of publications, was occurring in California (see **Exhibit 8**). The University of California system (the Santa Barbara and Berkeley campuses in particular), CalTech, JPL, and the IBM Almaden Research Center were all active in the area of quantum computing (see **Exhibit 9**). Silicon Valley was also home to many potential co-developers and customers, including firms in computing, the life sciences, and nanotechnology. Finally, not only was DFJ located in the Silicon Valley, but one third of all US venture capital was from this region.[9]

Maryland

Maryland was a possible location for D-Wave's headquarters because of the strong military presence in the state. Both the National Security Agency (NSA) and the Central Security Services, the US agencies responsible for information systems security and cryptology efforts, were based in Maryland. In terms of a co-development partner or as a possible exit strategy, Rose realized that the US military would be interested in the potential code-breaking capabilities of quantum computers.[10] But Maryland also prided itself on being at the forefront of biotechnology, boasting more than 300 biosciences companies and federal institutions, including the National Institution of Health and the US Food and Drug Administration.[11] Maryland-based company Celera Genomics had been in the headlines often during 2001 for its work on the Human Genome Project.[12] The state had established a populous scientific community, largely due to the presence of federal institutions such as NASA and the National Institute of Standards and Technology, as well as academic institutions such as John Hopkins University and the University of Maryland.

Jena, Germany

The greatest concentration of scientists working within the D-Wave network was currently located in Jena. With successful collaboration agreements in place with the Institute for Physical High Technology in Jena as well as the University of Erlangen, D-Wave was well positioned to establish a facility in Jena. If it did, it was likely that D-Wave would retain most of their German scientists. Recently, Jena had become recognized as a biotechnology cluster in Europe; companies such as Jena Drug Discovery, Jena Bioscience GmbH, and JenLab GmbH were located there. Because of the ease of access to larger German cities such as Munich and Berlin, Jena had become a desirable

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[9] "Why Locate in Silicon Valley?" Nanotech Associates. http://www.nanotechassociates.com/WhySV/

[10] http://www.nsa.gov/about_nsa/nsa_role.html

[11] "Top ten reasons to locate in Maryland." http://www.choosemaryland.org/orientation/topten.asp

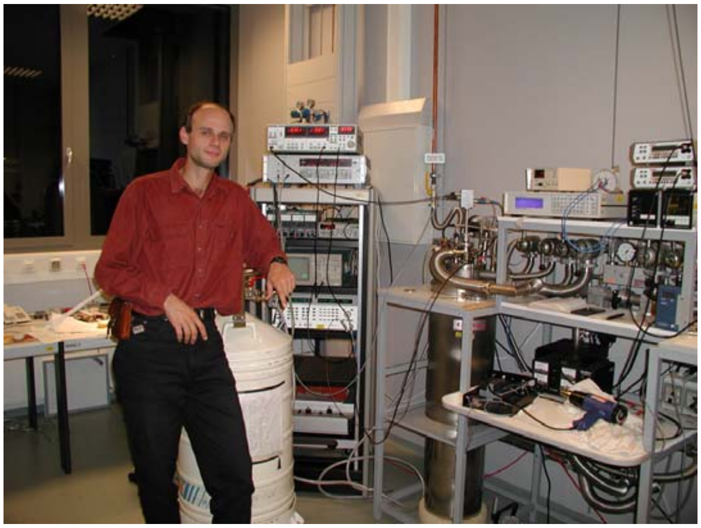
[12] "On the threshold of a brave new world." http://www.cnn.com/SPECIALS/2000/genome/story/overview/

environment for young companies.[13] Finally, several prominent high-tech investment companies such as Deutsche Effecten- und Wechsel-Beteiligungsgesellschaft AG (DEWB) were located in Jena.

Rose logged into his email, and watched as a torrent of spam began accumulating in his in-box. Aha, he thought, another great application for a quantum computer…

[13] BioCentiv GmbH. http://www.biocentiv.com/haupt.htm

Exhibit 1 Photographs of the Superconducting Quantum Computer System



The entire superconducting QC system

The "cold finger" which holds the QC chip (the cold finger is submerged in the white barrel that appears in the photo above)

QC chips, which are aluminum and niobium on sapphire – they are mounted at the bottom of the cold finger

Source: Photos courtesy of D-Wave Systems

Exhibit 2 D-Wave Timeline for Building a Quantum Computer

Number of qubits achievable per chip	Year end	Technology Required for Real-time Simulation of QC	Better than Silicon?
1	2002	Pencil & Paper (1900s)	No
2	2003	Vacuum Tube Computers (1940s)	No
4	2004	Early Microcomputers (1960s)	No
8	2005	486-class PCs (1990)	No
16	2006	64-bit SunFire 12K (2003)	Borderline
32	2007	Eight Networked SunFire 15Ks (2004)	Yes
64	2008	5 Million Times all Computers Ever Built as of 2008	Yes

Source: D-Wave Business Plan, November 2002

Exhibit 3 Distribution of Patents Issued by Organization

Organization	Location	No. of Patents Issued
D-Wave Systems	Canada (BC)	11
IBM Corp.	New York	2
Silicon Graphics, Inc.	California	1
Lucent Technologies Inc.	New Jersey	1
Hitachi, Ltd.	Japan	1
Kumamoto University	Japan	1
Victoria Univ. of Tech.	Australia	1
Unisearch Ltd.	Australia	1

Source: U.S. Patent and Trademark Website <http://www.uspto.gov>

Note: This list includes all patents with the term "qubit(s)" in either the title or the abstract that were issued before December 15, 2003.

Exhibit 4 Distribution of Patent Applications by Organization

Organization	Location	No. of Patent Applications
D-Wave Systems	Canada (BC)	26
Hitachi, Ltd.	Japan	3
IBM Corp.	New York	1
University of Calgary	Canada (AB)	1

Source: U.S. Patent and Trademark Website <http://www.uspto.gov>

Note: This list includes all patent applications with the term "qubit(s)" in either the title or the abstract that were pending as of December 15, 2003.

Exhibit 5 Distribution of Quantum Computing Research Activity by Type of Institution (1999-2000).

Rank	Institution Type	Weighted Publishing Activity	% of Total
1	University/College	10186	77%
2	Corporation	1647	12%
3	Public Institution	1447	11%
	Total	13279	100%

Source: Data Compiled from ISI Web of Science

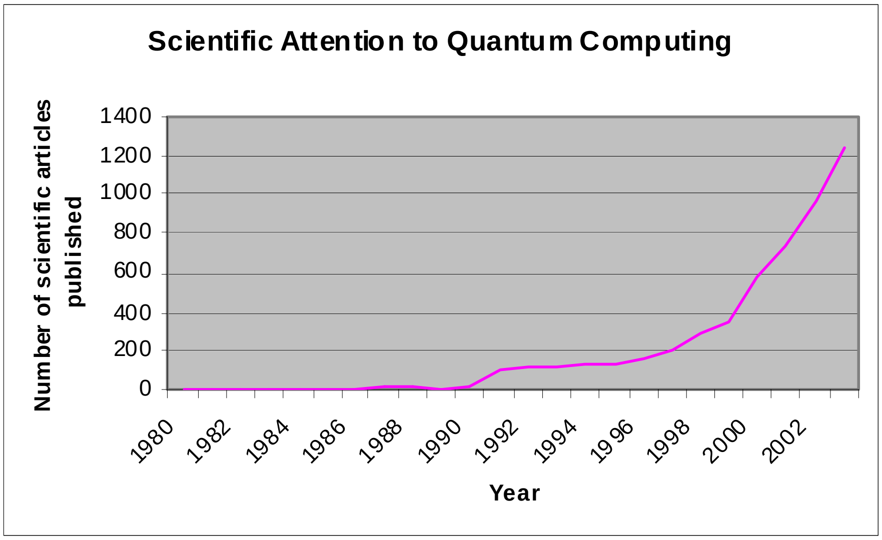
Method: Publications counted include those that contain the term "qubit" or "entanglement" with false positives removed (e.g., articles regarding fish entanglement were removed). Ranking by institute type is based on weighted publishing activity, calculated as follows:

$$w_i = \sum_{j=1}^{N} (Citations_j + 1) * \left(\frac{n}{m} \right)$$

where w_i is the weighting of the i^{th} institution type (or location or institution – see Exhibits 8 and 9) j is the publication, N is the total number of publications, $Citations_j$ is the number of times paper j has been cited by December 2003, n is the number of author addresses associated with publication j that are of institution type i, and m is the total number of addresses associated with publication j.

Note: The category "public institution" includes publicly funded institutions that are not universities or colleges such as the National Research Council of Canada, the National Institute of Standards and Technology, and the Max Planck Institut fur Informatik.

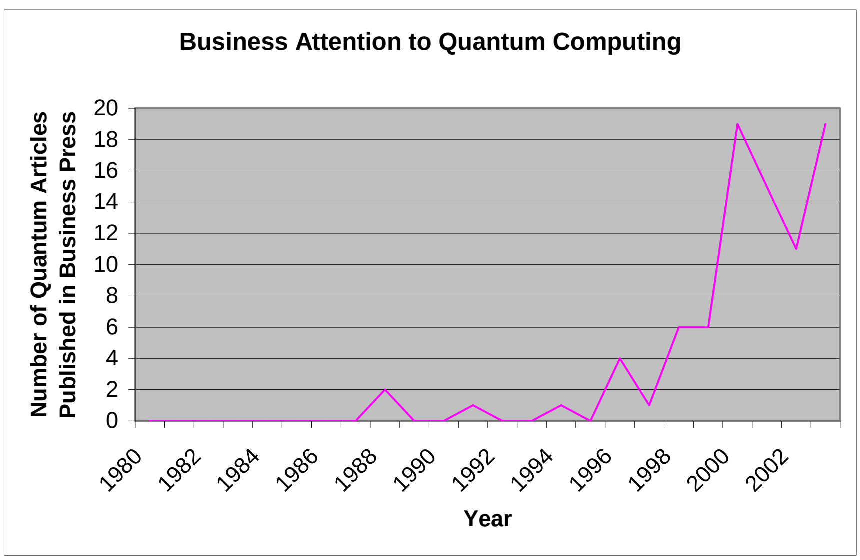
Exhibit 6 Scientific Attention to Quantum Computing



Source: Publication Data from ISI Web of Science

Note: Publications counted include those that contain the terms "qubit" or "entanglement" with false positives removed (e.g., articles regarding fish entanglement in nets were removed).

Exhibit 7 Business Attention to Quantum Computing



Source: Publication Data from ISI Web of Science

Note: Publications counted include those containing the term "qubit" or "quantum computer" or "quantum computing." Articles were limited to the ABI Inform database, which includes such global business publications such as the Economist, Business Week, Scientific American, Technology Review, and the Wall Street Journal.

Exhibit 8 Distribution of Quantum Computing Research Activity by Location (1999-2000)

Rank	Geography	Weighted Publishing Activity	% of Total
1	California	1309	9.9%
2	England	1214	9.1%
3	Austria	973	7.3%
4	Japan	929	7.0%
5	New York	787	5.9%
6	Germany	673	5.1%
7	Massachusetts	530	4.0%
8	Switzerland	523	3.9%
9	France	520	3.9%
10	Poland	460	3.5%
87	British Columbia	1	0.0%
	Rest of World	5359	40.3%
	Total	13284	100%

Source: Publication Data from ISI Web of Science (Publications weighted by method described in Exhibit 5)

Exhibit 9 Distribution of Quantum Computing Research Activity by Institution (1999-2000)

Rank	Institution Name	Total	% of Total
1	Innsbruck Univ	903	6.82%
2	IBM Corp	679	5.13%
3	Univ Calif Santa Barbara	440	3.32%
4	Univ London Imperial Coll Sci Technol & Med	343	2.59%
5	CALTECH	317	2.40%
6	Ecole Normale Super, Lab Kastler Brossel, Paris, France	291	2.20%
7	Univ Oxford	285	2.15%
8	NEC Fundamental Res Labs, Ibaraki, Osaka, Japan	275	2.08%
9	Univ Sci & Technol China	254	1.92%
10	Univ Gdansk	230	1.74%
11	Univ Basel	220	1.66%
12	Univ Calif Los Alamos Natl Lab	218	1.65%
13	Univ Calif Berkeley	213	1.61%
14	Aarhus Univ	210	1.59%
15	Univ Barcelona	207	1.57%
16	AT&T Shannon Lab, Florham Park, NJ	207	1.56%
17	Univ Geneva	202	1.53%
18	MIT	192	1.45%
19	Harvard Univ	179	1.35%
20	Univ Maryland Baltimore Cty	146	1.10%

Source: Publication Data from ISI Web of Science (Publications weighted by method described in Exhibit 5)

Appendix A

Excerpt from Sample Research Collaboration Agreement

THIS AGREEMENT made effective as of XXX.

BETWEEN:

D-WAVE SYSTEMS INC.,

(hereinafter called "D-Wave")

OF THE FIRST PART

AND:

XYZ Research Institution,

(hereinafter called "RESEARCH INSTITUTION")

OF THE SECOND PART

WITNESS THAT WHEREAS:

A. D-Wave is engaged in the business of designing and patenting hardware and software components of quantum computing systems;

B. RESEARCH INSTITUTION is a research institute that, among other things, contracts with private industry to carry out applied research;

C. D-Wave is willing to pay to RESEARCH INSTITUTION a per annum rate to fund certain scientific developments set out in Schedule "A" to this agreement (the "Developments");

D. D-Wave wishes to retain the services of certain scientists at RESEARCH INSTITUTION, and RESEARCH INSTITUTION wishes to make their services available to D-Wave to carry out the applied research set out in Schedule "A" to this Agreement;

THEREFORE, in consideration of the promises and the mutual covenants contained herein, the parties hereto agree as follows:

SECTION 1 – DEFINITIONS

Deleted

SECTION 2- TERM

Deleted

SECTION 3- PROJECTS AND REPORTS

RESEARCH INSTITUTION hereby agrees:

3.1 to conduct the work on the Project in a timely and efficient manner and in accordance with the Implementation Schedule;

3.2 that if any Development is not provided to D-Wave on or before the respective date set out in the Implementation Schedule, then D-Wave may, in its sole option, either (i) extend the relevant delivery date or (ii) terminate the Project by written notice to RESEARCH INSTITUTION with thirty (30) days' notice; and

3.3 to provide oral and written progress reports to D-Wave when and if reasonably requested by D-Wave, but in the absence of any request from D-Wave, a written progress report ("Progress Report") shall be due to D-Wave on the anniversary of every three month period ("Quarter") from the date first written above.

SECTION 4 - PAYMENT

4.1 D-Wave agrees to pay RESEARCH INSTITUTION for work performed by the Lead Scientist Group on the Project at the per annum rate of $XXX, payable in instalments quarterly as follows: (i) 70% of the quarterly payment will be paid in advance, on the first day of the Quarter; and (ii) 30% of the quarterly payment will be paid in arrears, and will be paid upon receipt by D-Wave of the Progress Report for that Quarter. D-Wave must provide written acknowledgement of the receipt of failure to receive the Progress Report, and make the outstanding portion of the payment within fourteen (14) days after the receipt of the Progress Report. If the Progress Report for any Quarter is not received by D-Wave within thirty (30) days following the end of that Quarter, this portion of the quarterly payment will be permanently forfeited by RESEARCH INSTITUTION. In cases of Force Majeure (e.g. illness of Lead Scientist or key personnel from his group or in the case of an accident of Lead Scientist or from key personnel from his group) the quarterly payment won't be permanently forfeited. In such cases RESEARCH INSTITUTION will inform D-Wave as soon as possible about those circumstances and both partners will agree a new date for the submission of the Progress Report.

4.2 D-Wave agrees that if D-Wave fails to pay on the respective dates set out in this Agreement, RESEARCH INSTITUTION may, in its sole discretion, terminate the Project upon providing ninety (90) days' written notice to D-Wave.

4.3 RESEARCH INSTITUTION agrees that it is responsible for all taxes which may be payable or collectable now or in the future as a result of this Agreement, including without limitation goods and services tax.

SECTION 5 - INTELLECTUAL PROPERTY OWNERSHIP

5.1 RESEARCH INSTITUTION agrees that:

(a) D-Wave shall be and, at all times shall remain, the exclusive owner of all the Developments and all related material, including all trade secrets, copyright, patent and other intellectual and industrial property rights therein (the "Intellectual Property");

(b) D-Wave is hereby assigned all right, title and interest in and to the Developments and all related material and any interest therein which any member of Lead Scientist's Group may make or obtain in the course of their work on the Project, effective as at the time each is created;

(c) RESEARCH INSTITUTION will make its best efforts to ensure that the individual members of Lead Scientist's Group irrevocably waive in favour of D-Wave any and all moral rights that they have or may have in and to the Developments and all related material;

(d) RESEARCH INSTITUTION will make its best efforts to ensure that the individual members of Lead Scientist's Group will execute such further documents and do such acts and other things reasonably requested by the D-Wave to evidence and effect such ownership, assignment and waiver, and to cooperate with D-Wave in each application or filing made or proposed by D-Wave with respect to the Developments or any related material as reasonably requested by D-Wave, in all cases both during the term of the Project and thereafter;

(e) the costs for filing and maintaining all patents associated with the Developments shall be borne by D-Wave; and

(f) Lead Scientist is allowed to use the Intellectual Property for the purposes of his ongoing scientific research, but this subparagraph does not convey a right to sub-license or use the Intellectual Property for any commercial purposes without D-Wave's prior written consent.

5.2 RESEARCH INSTITUTION represents and warrants to D-Wave as follows:

(a) no Developments delivered to D-Wave pursuant to this Agreement are actually known to RESEARCH INSTITUTION, including individual members of Lead Scientist's Group, to contain Intellectual Property which infringes any third party's patent or copyright;

(b) all Developments subject to patent protection created pursuant to this Agreement will be created by employees of RESEARCH INSTITUTION acting in the course of their employment or by independent contractors who are contractually obliged to transfer to RESEARCH INSTITUTION any intellectual property that is subject to patent or other forms of intellectual property protection, which they create for D-Wave in the course of their employment or retainer with RESEARCH INSTITUTION;

(c) none of RESEARCH INSTITUTION or any individual member of Lead Scientist's Group will grant to anyone other than D-Wave any rights, title or interest in or to any of the Developments or Intellectual Property created under this Agreement;

(d) title to the Developments and Intellectual Property created under this Agreement will pass to D-Wave free and clear of all encumbrances, charges, pledges, hypothecations, security interests, liens (whether statutory or otherwise), prior assignments or options to purchase;

(e) as of the date first written above, neither RESEARCH INSTITUTION nor any individual member of Lead Scientist's Group has knowledge of any claim, action, or demand against RESEARCH INSTITUTION or any individual member of Lead Scientist's Group or otherwise in respect of the Project and/or Developments; and

(f) RESEARCH INSTITUTION will immediately notify D-Wave should RESEARCH INSTITUTION or any individual member of Lead Scientist's Group become aware of any such claim, action or demand thereafter.

SECTION 6 - PUBLICATIONS

6.1 Without prejudice to any obligation of confidentiality in respect of another Party's information, all publications and oppositions pursuant to this Agreement shall be exercised as follows:

(a) In respect of publications, a copy of the planned publication (the "Planned Publication") shall be supplied to the other Party (the "Receiving Party") at least one month prior to its proposed date of publication. Any opposition to the Planned Publication shall be made by the Receiving Party within one month of receipt of the Planned Publication.

(b) When there is an opposition, the Parties shall discuss how to overcome the Justified Grounds of the opposition (for example by amendment to the Planned Publication) and the opposing Party shall not unreasonably continue the opposition if appropriate actions are performed following the discussion. If the Receiving Party requests a delay in publication of up to ninety (90) days (the "Delay"), then neither Party shall publish the Planned Publication during the Delay.

6.2 The Justified Grounds of opposition are:

(a) for business or academic reasons concerning the inclusion of the opposing Party's trade secrets or Developments.

(b) for protection reasons concerning Developments, where the publication of the material identified in opposition would adversely affect such protection.

6.3 In the case of Section 6.2(b) of this Agreement, the Parties concerned shall co-operate to achieve such protection in respect of Developments and to overcome such barrier to publication. The opposing Party may in no event delay publication more than six months from receipt of a copy of the Planned Publication.

SECTION 7 - CONFIDENTIALITY

7.1 With respect to all information, including Developments, of whatever nature or form as is disclosed under this Agreement by one Party (the "Discloser") to another Party (the "Disclosee") that:

(a) is clearly marked "confidential";

(b) if disclosed orally, was at the time of disclosure indicated to be "confidential" and within thirty days reduced to physical form and marked "confidential" by the Discloser; or

(c) is obviously of a confidential nature,

each Party agrees that such information is communicated on a confidential basis and its disclosure to someone who is not a Party to this Agreement may be prejudicial to the owner of the information, and the Disclosee undertakes that:

(d) it will not during a period of three (3) years from the date of disclosure to it use any such information for any purpose other than in accordance with the terms of this Agreement; and

(e) it will during the period of three (3) years treat the same as (and use reasonable endeavours to procure that the same be kept) confidential and not disclose the same to anyone who is not a Party to this Agreement without the prior written consent of the owner in each case;

provided always that:

(f) such agreement and undertaking shall not extend to any information which the Disclosee can show:

(i) was at the time of disclosure to the Disclosee published or otherwise generally available to the public, or

(ii) has after disclosure to the Disclosee been published or become generally available to the public otherwise than through any act or omission on the party of the Disclosee; or

(iii) was already in the possession of the Disclosee, without any restrictions on disclosure, at the time of disclosure to the Disclosee, or

(iv) was rightfully acquired by the Disclosee from a third party without any undertaking of confidentiality; or

(v) was developed independently of the work under the Agreement by the Disclosee.

7.2 Nothing in this Section 7 shall prevent the communication of information as is needed to be communicated to comply with applicable laws or regulations or with a court or administrative order, provided that before the Disclosee discloses such confidential information in order to comply with such a law or order, the Disclosee will make its best efforts to inform the Discloser of the need for such disclosure and will limit such disclosure to the minimum disclosure that is required to comply with said law or order.

SECTION 8 - FURTHER RESEARCH AND AGREEMENT OF RESEARCHERS

8.1 The Parties hereby grant to each other, as of the date first written above, a right to use, free-of-charge, Project results for internal research in subsequent research activities.

8.2 RESEARCH INSTITUTION agrees to require as a condition of the participation of any researchers, postdoctoral student, technician or other staff member of RESEARCH INSTITUTION in Lead Scientist's Group, that each of the participants shall acknowledge and indicate their agreement to comply with the terms of this Agreement, and in particular Article 5 above by signing the acknowledgement in the form set out in Schedule "C" to this Agreement.

8.3 RESEARCH INSTITUTION agrees to enforce the compliance of the other members of Lead Scientist's Group with the terms of the acknowledgment set out in Schedule "C" and that if one or more of the members of Lead Scientist's Group breaches the terms of the acknowledgement, that is a breach of this Agreement.

SECTION 9 - LIABILITIES

9.1 In respect of information or materials supplied by one Party to another hereunder, the Party supplying such information or materials shall be under no obligation or liability to the other Party, and no warranty condition or representation of any kind is made, given or to be implied as to the sufficiency, accuracy or fitness for commercial or any other purpose of such information or materials, or (with the exception of the representations and warranties provided pursuant to Section 5 of this Agreement), the absence of any infringement of any proprietary rights of third parties by the use of such information and materials and the recipient Party shall in any case be entirely responsible for the use to which it puts such information and materials.

9.2 Each party shall be solely liable for any loss, damage or injury to third parties resulting from its carrying out its parts of the Project and from its use of Project results.

SECTION 10 - FORCE MAJEURE

10.1 A failure in the performance of this Agreement cannot be imputed or assumed to a Party to the extent it is due to "Force Majeure". The expression "Force Majeure" shall mean any unforeseeable and insuperable event affecting the Party in fulfilling its obligations hereunder.

SECTION 11 - NO PARTNERSHIP OR AGENCY

11.1 Nothing in this Agreement shall create a partnership or agency between the Parties.

SECTION 12 - ASSIGNMENT

12.1 No Party shall, without the prior written consent of the other Party, assign or otherwise transfer partially or totally any of its rights and obligations under this Agreement. Such consent shall not be unreasonably withheld when such assignment or transfer is in favour of an affiliate of that Party.

SECTION 13 - TERMINATION

13.1 After signature of this Agreement, no Party shall be entitled to withdraw from its participation in the Project unless that Party has obtained the prior written consent of the other Party (such consent not to be unreasonably withheld) for six months.

13.2 After six months have elapsed, D-Wave shall be permitted to terminate the project upon the giving of thirty (30) days' written notice to RESEARCH INSTITUTION.

13.3 In the event that D-Wave terminates the Project, D-Wave shall be obligated to pay RESEARCH INSTITUTION on a pro rata basis for the time until the termination takes effect.

Remaining Sections Deleted

SCHEDULE "C"

CONFIDENTIAL INFORMATION AND INTELLECTUAL PROPERTY AGREEMENT

Anonymous Research Institution ("RESEARCH INSTITUTION") may make information and facilities for research available to me in connection with my work under a contract (the "Research Agreement") between RESEARCH INSTITUTION and D-Wave Systems Inc. (the "Company") for the Project (as that term is defined in the Research Agreement). In consideration of the information and facilities made available to me and other valuable consideration, I agree that:

1 I will keep confidential in accordance with the terms of the Research Agreement, all of the Company's confidential information that I may receive, and I will also keep the terms of the Research Agreement confidential.

2. I will comply with all publication conditions that may be set out in the Research Agreement.

3. I will comply with all conditions regarding Intellectual Property that may be set out in the Research Agreement.

4. All decisions about the protection of Intellectual Property under applicable legislation, ownership of and rights in any resulting application or patent, and revenue from Intellectual Property will be made in accordance with the Research Agreement, and I will accept such decisions as final.

5. I will sign all documents and do all things necessary or proper to give effect to this Agreement and any rights granted by RESEARCH INSTITUTION to the Company under the Research Agreement.

6. I have had an opportunity to review the applicable terms of the Research Agreement and obtain advice on the Research Agreement and my obligations under this Agreement.

By signing below, I indicate my acceptance of the above terms and conditions:

____

(Signature of Researcher)

____

(Print full name of Researcher)

____

(Date)

Appendix B

Excerpt from Intellectual Property Review Letter

As requested by D-Wave, we have conducted a review of the processes and procedures used by D-Wave Systems (hereinafter D-Wave) to protect its Intellectual Property (IP). We have also provided patentability opinions for five patent applications selected by D-Wave.

PROCEDURES

Based on our discussions with the IP personnel at D-Wave, it appears that D-Wave has implemented numerous procedural and contractual safeguards to prevent unauthorized disclosures of the IP and to identify those portions of the IP that should be protected by patents. D-Wave also appears to have implemented a comprehensive and thorough process for locating prior art that may be material to the patentability of the inventions disclosed in the D-Wave patent applications.

Systems for Preventing Premature Disclosure

It is our understanding that D-Wave has agreements and procedures in place to prevent unauthorized or premature disclosure of the IP owned by D-Wave. For regular employees, D-Wave has stressed the importance of protecting the IP from unauthorized disclosure. For outside contractors, especially, those contractors working for universities, D-Wave has publication agreements in place. We have not reviewed these agreements, but it is our understanding that in all cases D-Wave has the right to delay publication of information until such time as D-Wave has reviewed the information and filed patent applications if the information describes inventions that are deemed to be valuable. In our opinion, the approach taken by D-Wave is reasonable, prudent, and cost-effective.

Systems for Producing Evidentiary Documentation of Invention Dates

U.S. patent law is unique in that the date that an invention was first conceived can be important in determining who, among several competing parties, was the first to invent and therefore is entitled to obtain a patent. In addition to the date of conception, it is sometimes necessary to prove that the first inventor was diligent in pursuing the invention, either by reducing the invention to practice or by filing a patent application. For these reasons, it is advisable to keep records regarding the date of conception and subsequent activities related to the invention up until the filing of an application. One traditional method for maintaining such records is to require each inventor to keep an inventor's notebook. Unfortunately, many inventors chafe at this notion, and it can be difficult to enforce a notebook policy. It is particularly difficult to enforce such a policy when dealing with outside contractors.

In view of these difficulties, it is our understanding that D-Wave conducts semi-weekly science meetings to review progress on the D-Wave IP. Researchers (inventors) working for D-Wave provide at least a weekly verbal report on progress, ideas, etc. A written report is produced from each meeting. These written reports are intended to provide a documentary record of the inventions produced by D-Wave and the development of those inventions.

We recommend that each inventor also be required to keep an inventor notebook, and that these notebooks be regularly witnessed.

Procedures for Non-Disclosure Agreements

As discussed above, it is our understanding that when dealing with outside entities, it is the policy of D-Wave to obtain agreements that allow D-Wave to restrict disclosure or use of confidential information relating to D-Wave IP. We have not reviewed these agreements, but understand from our discussions with D-Wave personnel that they include normal and effective clauses.

Procedures for Obtaining and Prioritizing Invention Disclosures

As discussed briefly above, the Intellectual Property (IP) group at D-Wave conducts regular science meetings to review the IP being developed by D-Wave. From these science meetings, a list of inventions is generated and prioritized. The inventions are prioritized based on their expected value to D-Wave and in view of the known prior art. From this prioritized list, the IP group selects those inventions that will form the basis for the patent applications filed by D-Wave.

Search Procedures

D-Wave appears to have implemented a comprehensive search strategy to identify prior art in the field of quantum computing. This search includes: patent searching for recently published patent applications and recently issued patents related to quantum computing; review of scientific journals that publish articles pertaining to quantum computing (e.g., Nature, Phys. Rev., IEEE Transactions, etc.); conference proceedings; etc. Since the field of quantum computing is relatively new, it is likely that D-Wave has identified the bulk of the prior art currently available on this subject.

Procedures for Preparing and Filing Patent U.S. Applications

It is our understanding that the D-Wave process for preparing and filing patent applications is complete and thorough. Prior to involvement by counsel, the process includes: identifying the inventor(s), obtaining an invention disclosure from the inventor(s); drafting proposed claims; searching the prior art; drafting the application; technical review of the application for possible design-arounds, completeness, etc.; and review by the inventor(s). The application is then sent to outside counsel for review and possible revision before filing.

STRATEGIC APPROACH

Based on our discussions with the IP personnel at D-Wave, and based on a review of a sampling of five D-Wave patent applications, it appears that the strategic approach adopted by D-Wave for protecting its IP is comprehensive and sound.

Overall Patent Strategy

The D-Wave patent strategy appears to be designed to seek protection of all elements of quantum computing IP developed by D-Wave within the allowed budget. It is our understanding that inventions are identified and prioritized with a view towards seeking patent protection for those concepts that are likely to be of most value to D-Wave. D-Wave has filed applications covering diverse technology areas related to quantum computing, including, but not limited to, structures for quantum computers, fabrication techniques for quantum computers, control systems for quantum computers, algorithms for quantum computing, optimization methods for quantum computing, etc. This broad strategy appears to be designed to seek vertically-integrated control of virtually all levels of quantum computing, from the lowest hardware levels to the highest programming abstraction levels.

Claim Strategy

In reviewing the five applications discussed below, it appears that D-Wave is seeking a broad mix of claims, including apparatus claims, method claims, and means-plus-function claims. This is a prudent approach as each type of claim has different strengths and weaknesses. We have not reviewed the claims of any D-Wave applications other than the five listed below.

Continuation Strategy

At present, none of the D-Wave patent applications are in the issue process, and thus no continuations have been filed. It is our understanding that the IP group and D-Wave will review the need for continuations when the time comes.

Other Forms of Protection

It is our understanding that D-Wave has, at this time, not sought protection for the scientific IP through means other than utility patents (e.g., design patents, copyrights, mask works protection, etc.) However, it is our understanding that D-Wave will continue to evaluate the IP on a case-by-case basis with a view to seeking such protection when appropriate.