Testimony of Scott Crowder
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Introduction

Chairwoman Comstock, Chairman Weber, members of the subcommittees. Thank you for inviting me here to testify this morning. My name is Scott Crowder and I am IBM's Vice President and Chief Technology Officer for Quantum Computing.

Quantum computing is not just another emerging technology. It is a radically different computing paradigm that could launch a new age of human discovery. The technology will one day help us to solve problems that are unsolvable today with classical computer systems. You are right to focus on U.S. quantum leadership given its critical importance to our national competitiveness and security.

For the purposes of this hearing, I will focus on the commercial significance of quantum computing. IBM's position is that the commercial world should begin to experience the first benefits from approximate forms of quantum computing within a few years.

In my testimony today, I will provide a brief overview of what differentiates quantum computers, the current state of the technology, our longer-term roadmap and how government can help advance quantum research. I'll also touch on the status of quantum research in other countries, and the critical need to develop human skills training in quantum computing here in the U.S.

Why quantum computing is different

Quantum theory changed the world in the early 20th century by explaining the bizarre behavior of subatomic particles. After decades of research, much of it led by IBM, we can now exploit the laws of quantum mechanics in a way that gives us a potential "quantum advantage" in conducting certain calculations that conventional computers cannot manage alone.

This development couldn't come at a more important time. For more than 50 years computing has been guided by Moore's Law: the observation that the number of transistors per square inch on integrated circuits will double every year. This fundamental insight made the technology revolution and everything that defined it possible, from home computers to supercomputers to smartphones. But as we approach the physical limits of silicon-based technology, we must look to new methods to expand computational power. Quantum computing is one of our best hopes.

Quantum computers follow a different set of rules from classical computers. Rather than bits, quantum computers use qubits, or quantum bits, which can exist in a much richer set of computational states. This allows us to rethink the *way* we solve problems and utilize algorithms that can, for a number of important applications, exponentially exceed the capabilities of a traditional computer. It also opens the opportunity to tackle problems that have long been considered out of bounds because of memory, processing, or time.

Take the challenge of chemistry. If we could truly simulate the behavior of atoms and molecules, their energies and interactions, we could do amazing things, like develop new, life-saving drugs in a fraction of the time it takes today. Unfortunately, this task lies far beyond the capacity of conventional computers. There's no realistic way we'll get there with a system based on current technology. In fact, simulating a relatively simple molecule like caffeine would require a classical computer roughly 1/10th the size of planet Earth.

Using quantum chemistry, we could model and research new chemical compounds that lead to stronger, lighter, more efficient materials. These materials could be less expensive to manufacture for use in everything from clothing to airplanes. Airplane manufacturers could use these breakthroughs to design more durable, lighter airplanes that are even safer, while reducing fuel use and the costs to passengers.

Another activity quantum computers could excel at is optimization: finding the best answer when there is a huge, exponential number of possibilities. For example, no classical computer alone can determine the optimal routes, costs, and delivery schedules of 5,000 trucks while accounting for payload, gas mileage, time, weather, and traffic, all of which are changing in real time. With each new variable, the number of possible outcomes increases exponentially. However, quantum computers could potentially solve such a problem in no time.

Food supply is another problem ripe for quantum solutions. Current synthetic fertilizers are less effective than natural fertilizers because we cannot yet model the complex combinations of their components. With enhanced fertilizers developed with quantum computing models, farmers could grow more food in less space to feed the world's growing population. In this way, we could better address food shortages and lower environmental impacts.

The state of quantum technology today

Quantum computers share another defining characteristic. They are extremely complex and challenging to build. Quantum states are exquisitely fragile and delicate. Anything can interfere with the successful functioning of the chip such as heat, noise or electromagnetic waves. For that reason, we keep our chips inside a refrigerator that is colder than outer space. It requires intricate engineering to maintain the quantum state of 'coherence' – the lifetime of quantum information – and perform calculations, while sending signals in and out of the system to know what the calculations are.

Existing quantum machines are still too small to fully solve problems more complex than supercomputers can handle. Nevertheless, we've made tremendous progress. The day when quantum computers exceed the capacity of classical machines is now in sight. Let me illustrate this with a few highlights of key developments at IBM.

We've developed algorithms that will run faster on a quantum machine. We now have techniques that prolong coherence in superconducting quantum bits by a factor of over 100 compared to 10 years ago.

We achieved breakthroughs in methods to detect and measure the two types of errors that will occur in any real quantum computer, known as bit-flip and phase-flip. This was a necessary step toward quantum error correction, a critical requirement for building a practical and reliable large-scale quantum computer.

IBM Research has already built and deployed functioning 5-qubit and 16-qubit universal quantum computers and made them available to the public over the cloud. This distinction of "universal" is important. It is the only class of quantum computer that has been proven theoretically to vastly accelerate the solution to certain problems. Thousands of academics and enthusiasts on all seven continents have used access to the IBM quantum cloud service more than a million and a half times to do research, publish papers, educate students, and perform new computations.

Earlier this year, IBM launched the industry's first commercial program to provide access to universal quantum computers, called IBM Q. As part of that program, we will enable IBM clients to use a more powerful 17-qubit processor through the cloud. They can take advantage of it to explore what they will eventually do with this technology. In the not-too-distant future we expect to scale the system to 50 qubits.

It's important to note that quantum computers will augment, not replace, classical computers. They will be used chiefly to handle specific types of problems, while classical computers will continue to advance for the tasks that they are good for. The most powerful systems of the next decade will be hybrids of quantum computers using classical computers to control logic and operations with large amounts of data. For example, quantum computing will improve artificial intelligence and machine learning by finding the best answers within a huge, exponential number of possibilities.

I hope I've conveyed that quantum computing is real, and its impact on our world is imminent. We at IBM are building universal quantum computers today and people are using them. Now is the time for the federal government to help expedite advancements in the technology to maximize its benefits for the country. Similar efforts are taking place elsewhere and it is imperative for the U.S. to keep up.

The importance of skills development

Training a new generation of people skilled in quantum computing is critical. That's why we launched the IBM Q experience interactive website in May 2016.

To give you some idea of its impact, there are approximately 2,000 experts in quantum information science in the world. But more than 50,000 people have accessed the IBM Q experience, explored our tutorials, and run experiments on our real 5-qubit and 16-qubit processors. Students in the U.S. from more than 500 academic institutions are using the IBM Q experience and the quantum software-development kit for education and skill development. This is but one example of how we can begin to grow the quantum ecosystem and the number of those who are familiar with this technology.

As we have built our quantum computing effort, we have identified three areas where there are skill shortages that must be addressed. Those countries that create the most effective partnerships between industry, academia and government to develop these skills will have a significant competitive advantage.

The first area is the development of quantum system hardware. The most critical skill areas we see in hardware development are cryogenics, FPGA programming, superconducting materials development and microwave engineering. There is some opportunity for mid-career re-training of engineers and research scientists to meet the skill demands. However, targeted research in these fields at graduate degree programs and curriculum within technical undergraduate programs will be required to satisfy future demand.

The second skill area is deep quantum information science expertise. This is necessary to drive both quantum computer and algorithm development. It requires a strong focus at the undergraduate and graduate levels as well as targeted post-doctoral research. Creation of quantum information science disciplines and funded research in that field is paramount to strengthening this critical skill.

The third skill area is quantum application and solution developers. The IBM Q experience helps by providing useful educational tools and our open source QISKit is the start of the first software-development kit. They reduce the barrier to entry for new programmers, but more needs to be developed.

Those countries that undertake targeted research that benefits quantum computation in academic and government research institutions will enjoy a significant advantage. Furthermore, government and industry and must partner together to ensure that these institutions and early industry adopters have access to commercial quantum computers.

Global competition

The U.S. still leads the world in areas such as patents in quantum computing, but competition from other countries is rising sharply. Federal grant-making to universities and other partners for core quantum research and development remains significant, but is also rapidly being eclipsed by other governments. As a result, our belief is that the

U.S. government's investment in quantum technology is not sufficient to stay competitive. The race is on, and the field is rapidly expanding. Countries large and small are using novel forms of public-private partnerships to promote quantum commercialization. Let me touch on a few.

Canada has launched a national initiative to grow that country's vibrant quantum ecosystem. Known as Quantum Canada, it seeks to preserve Canada's advantage in quantum technologies and expand them for long-term economic prosperity. In September of last year, Canada committed $76 million to the Transformative Quantum Technologies program at the University of Waterloo.[1] The goal is to tackle three challenges in quantum research: development of a universal quantum processor, quantum sensors and long-distance quantum communications

Australia also announced an AUD $25 million investment for a total of 5 years to help develop a silicon quantum integrated circuit, a critical step in building a functional quantum computer. The funding has been allotted to the University of Sydney and the University of New South Wales.[2]

The European Commission announced last year that it would create a €1-billion research effort called the Quantum Technology Flagship. The focus will be on four quantum technologies: communication, computing, sensing and simulation.[3] A McKinsey consulting report estimated that the European Union had more than twice the number of quantum researchers and one-and-a-half times the funding for quantum compared to the United States.[4]

The government of China's deep and growing support for quantum research is well known. Quantum technologies are viewed as vital to national security and to strategic competition. Quantum computing holds a prominent place in China's Five-year National

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[1] Government of Canada. 2016. "Government of Canada invests $900 million to transform university research." Canada First Research Excellence Fund. September 6. http://www.cfref-apogee.gc.ca/news_room-salle_de_presse/press_releases-communiques/2016/University_of_Waterloo-eng.aspx

[2] Government of Australia. 2016. "Advancing quantum computing technology," Australian Government National Innovation and Science Agenda. http://www.innovation.gov.au/page/advancing-quantum-computing-technology

[3] Gibney, Elizabeth. 2016. "Europe plans giant billion-euro quantum technologies project." *Nature*, April 26. http://www.nature.com/news/europe-plans-giant-billion-euro-quantum-technologies-project-1.19796

[4] Hofman, Sander. 2016. "Start your engines! The race to quantum computing is on." *Medium,* July. https://medium.com/@ASMLcompany/start-your-engines-the-race-to-quantum-computing-is-on-14c3076a5c47

Science and Technology plans.[5] Construction is underway for a $10 billion research supercenter for quantum applications, called the National Laboratory for Quantum Information Science.[6] Chinese scientists estimate being able to create a 50 qubit quantum computer that could exceed the world's fastest supercomputer by 2020. The same McKinsey study estimates the country has more quantum researchers than the United States.

The Chinese government is working closely with industry partners to drive their national quantum agenda. Alibaba, along with the Chinese Academy of Sciences, has established the Alibaba Quantum Computing Lab with clearly defined, ambitious goals. These include launching a quantum cloud computing platform by 2017 and scaling up to 100 qubits by 2030.[7]

Recommendations for U.S. government

What can and must the U.S. do to keep pace with these efforts? Let me offer a few recommendations from an industry perspective.

Federal funding for basic quantum research enabled the U.S. to dominate the field of Quantum Information Science for decades. It made many subsequent breakthroughs in quantum computing possible. Now, in the face of intensive global competition, we believe the federal government must do more. It must play a key role in creating an environment within the United States that is better than any other country's at fostering the commercialization and growth of quantum computation.

As one relevant example of this, in the mid-1990s, the federal government funded a competition for the development of the world's highest performing supercomputers, called the Advanced Simulation and Computing Program, or ASCI. The goal was to find a way to test and maintain the nation's critical nuclear stockpile. The U.S. Department of Energy (DOE) defined a series of challenge problems to help American industry design the world's leading supercomputers. These powerful machines were built by a consortium of vendors including IBM. Not only was it successful in meeting its objectives, ASCI also went on to define U.S. leadership in the field of supercomputing

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[5] Costello, John. 2017. "Chinese Efforts in Quantum Information Science: Drivers, Milestones, and Strategic Implications." Testimony for the U.S.-China Economic and Security Review Commission. March 16. https://www.uscc.gov/sites/default/files/John%20Costello_Written%20Testimony_Final2.pdf

[6] Lin, Jeffery and P.W. Singer. 2017. "China is opening a new quantum research supercenter." Popular Science. October 10. https://www.popsci.com/chinas-launches-new-quantum-research-supercenter

[7] Costello. Chinese Efforts.

for years to come. The federal government should consider a similar program for quantum computing.

We support and commend the DOE's Office of Science program to create quantum computing testbeds. This effort should be significantly expanded to ensure that we're putting the most advanced quantum computers in the hands of U.S. research scientists and early industry adopters. This should include early stage commercial quantum computers from a variety of industry partners, not just IBM. In this way, we can ensure the exploration of various underlying quantum technologies.

We also need to do a lot more to build a generation of quantum information scientists to carry this technology forward. As one possibility, the federal government should look to fund the establishment of quantum centers at universities where students are introduced to quantum computing, see state-of-the-art technology, and work with industry. It could do the same within national laboratories to aid the commercialization of the technology. Government at the federal and state levels should work with industry and academia to create regional centers of excellence for quantum computing, along with topical centers of excellence for quantum-based solutions in areas such as computational chemistry and optimization.

Conclusion

We live in an age of astonishing progress in digital technologies. So it's surprising to many to hear that our intuition about what we can compute is often wrong. We tend to think classical computers can solve any problem if they are just big or fast enough. But that is not the case. There is a whole class of exponential problems that classical computers are not good at, and never will be. Quantum computing will enable us to overcome many of these intractable challenges and unleash untold economic benefits for society, if we seize this opportunity now.

I'm confident that we can and we will. America's track record in promoting historic scientific discovery is unmatched. It enabled us to establish the field of quantum information science and has led us to the doorstep of a new era of computing. With quantum technology about to assume a huge strategic importance, now is not the time to slow down. There is too much at stake to allow this country to fall behind. Our nation stands to benefit from quantum computers in ways we can't even imagine right now. The federal government should do everything in its power to ensure that we continue to lead the way towards a quantum future.