DISRUPTER SERIES: QUANTUM COMPUTING

HEARING

BEFORE THE

SUBCOMMITTEE ON DIGITAL COMMERCE AND CONSUMER PROTECTION

OF THE

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HOUSE OF REPRESENTATIVES

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DISRUPTER SERIES: QUANTUM COMPUTING

WEDNESDAY, MAY 18, 2018

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON DIGITAL COMMERCE AND CONSUMER PROTECTION,
COMMITTEE ON ENERGY AND COMMERCE,
Washington, DC.

The subcommittee met, pursuant to call, at 9:16 a.m., in room 2322, Rayburn House Office Building, Hon. Robert Latta, (chairman of the subcommittee) presiding.

Present: Representatives Latta, Lance, Guthrie, McKinley, Kinzinger, Bilirakis, Bucshon, Walters, Costello, Schakowsky, Welch, Kennedy, and Green.

Staff Present: Mike Bloomquist Staff Director; Margaret Tucker Fogarty, Staff Assistant; Melissa Froelich, Chief Counsel, Digital Commerce and Consumer Protection; Adam Fromm, Director of Outreach and Coalitions; Ali Fulling, Legislative Clerk, O&I, Digital Commerce and Consumer Protection; Elena Hernandez, Press Secretary; Paul Jackson, Professional Staff, Digital Commerce and Consumer Protection; Bijan Koohmaraie, Counsel, Digital Commerce and Consumer Protection; Peter Spencer, Senior Professional Staff Member, Energy; Andy Zach, Senior Professional Staff Member, Environment; Greg Zerzan, Counsel, Digital Commerce and Consumer Protection; Michelle Ash, Minority Chief Counsel, Digital Commerce and Consumer Protection; Jeff Carroll, Minority Staff Director; Caroline Paris-Behr, Minority Policy Analyst; and Michelle Rusk, Minority FTC Detailee.

OPENING STATEMENT OF HON. ROBERT E. LATTA, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF OHIO

Mr. LATTA. Good morning. And again, I would like to welcome you all to the Subcommittee on Digital Commerce and Consumer Protection here on Energy and Commerce. As I mentioned, we have another subcommittee that is running right now, so we will have members coming back from first floor, upstairs, during the committee from one to the other. But again, I do thank you all for being here today.

And I will recognize myself for my 5-minute opening statement. And again, welcome to the subcommittee in today's disruptor series hearing examining quantum computing. We continue our disrupter series as we examine emerging technology supporting U.S. innovation and jobs. This morning, we are discussing the revolutionary technology known as quantum computing. This involves harnessing the power of physics at its most basic level. Unlike the computers we are familiar with we use today, a quantum computer holds the potential to be faster and more powerful. This innovation is expected to change every industry and make problems that are impossible to solve today, something that can be solved in a matter of days or weeks.

Efforts to develop a commercially available and practical quantum computer are being pursued around the world. Because of the tremendous costs involved in developing a suitable environment for a quantum computer to operate, many of these efforts involve government support, both the European Union and China have pledged, or already have spent billions to develop a quantum computer.

In the United States, development of quantum computers is proceeding at the academic, governmental, and private sectors. In addition to the larger and familiar technology companies, smaller startups are also leading efforts in this area. We are fortunate to have one of these startups, IonQ, to testify today.

Although a quantum computer holds tremendous potential to solve previously noncomputable problems, there are skeptics who question whether it will be possible to ever develop such technology. We look forward to our witnesses giving us their thoughts on this question.

On the other hand, some fear that the threats such a computer would pose to the traditional computing model, especially when it comes to encryption and data security. Some fear that a quantum computer would make it nearly impossible to keep future computers secure. Data security and consumer privacy are key concerns of this committee.

We also look forward to our witnesses addressing this issue as well. Quantum computers hold tremendous potential to help solve problems involving the discovery of new drugs, developing more efficient supply chains and logistics operations, searching massive volumes of data, and developing artificial intelligence.

Whichever nation first develops a practical quantum computer will have a tremendous advantage over its foreign peers. We hope our witnesses will help us examine the state of the race to develop a quantum computer, and how the United States is doing in that race. This is obviously a very dense subject. We also understand there are several other areas under development leveraging the principle of quantum mechanics. Our goal today is simple: to develop a better understanding of the potential of quantum computers, the obstacles to developing this technology, and what policymakers should be doing to remove barriers and to help spur innovation, competition, and ensure a strong and prepared workforce for future jobs.

As we explore this topic today, I would, again, like to thank our witnesses for coming to share their expertise on this very complicated and revolutionary technology. I again appreciate you all being here today.

And at this time, I will yield back my time and recognize the gentlelady from Illinois, the ranking member of the subcommittee, for 5 minutes.

[The prepared statement of Mr. Latta follows:]

PREPARED STATEMENT OF HON. ROBERT E. LATTA

Good Morning. Welcome to the Digital Commerce and Consumer Protection Subcommittee, and today's Disrupter Series hearing examining quantum computing. We continue our Disrupter Series as we examine emerging technologies supporting U.S. innovation and jobs.

This morning we are discussing the revolutionary technology known as quantum computing. This involves harnessing the power of physics at its most basic level. Unlike the computers we are familiar with and use today, a quantum computer holds the potential to be faster and more powerful. This innovation is expected to change every industry and make problems that are impossible to solve today something that can be solved in a matter of days or weeks.

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In the United States, development of a quantum computer is proceeding at the academic, governmental and private sectors. In addition to larger and familiar technology companies, smaller start-ups are also leading efforts in this area. We are fortunate to have one of these start-ups, Ion-Q, to testify today.

Although a quantum computer holds tremendous potential to solve previously non-computable problems, there are skeptics who question whether it will be possible to ever develop such technology. We look forward to our witnesses giving us their thoughts on this question.

On the other hand, some fear the threat such a computer would pose to the traditional computing model. Especially when it comes to encryption and data security, some fear that a quantum computer would make it nearly impossible to keep future computers secure. Data security and consumer privacy are key concerns of this Committee. We also look forward to our witnesses addressing this issue as well.

Quantum computers hold tremendous potential to help solve problems involving the discovery of new drugs, developing more efficient supply chains and logistics operations, searching massive volumes of data, and developing artificial intelligence. Whichever nation first develops a practical quantum computer will have a tremendous advantage over its foreign peers. We hope our witnesses will help us examine the state of the race to develop a quantum computer, and state how the U.S is doing.

This is obviously a very dense subject. We also understand there are several other areas under development leveraging the principle of quantum mechanics. Our goal today is simple: to develop a better understanding of the potential of quantum computers; the obstacles to developing this technology; and, what policymakers should be doing to remove barriers and help spur innovation, competition, and ensure a strong and prepared workforce for future jobs.

As we explore this topic today, I would like to again thank our witnesses for traveling to DC and sharing their expertise with us as we examine this complicated and revolutionary technology. Thank you.

OPENING STATEMENT OF HON. JANICE D. SCHAKOWSKY, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF ILLINOIS

Ms. SCHAKOWSKY. Well, I want to thank you, Mr. Chairman. We continue our disrupter series with the exploration of quantum computing. I want to congratulate all of you for being so smart. Dr. Franklin, I was just told I think it was your mother and I graduated from the University of Illinois about the same time. This was a time before we knew anything about computers really, it was just beginning. And here you are today, the next generation leading us into the future. So I appreciate all of you being here today.

This technology, I understand, is still in the research phase, but the potential applications are tremendous, from healthcare to energy efficiency and everything in between. Given this potential, global competitors from the European Union to China are rushing to invest in quantum computing. The U.S. must make strategic investments if it wants to stay ahead. And those investments really start with STEM education. We must encourage students, including young women and students of color to pursue interests in computer science and physics. Fostering curiosity today prepares young minds to become great innovator of tomorrow.

As a former teacher myself, I strongly believe that our future economic success depends on investing in our children's education. Our research universities are leading the way on quantum computing. Public investment is crucial to develop technology until it can be profitable, possibly deployed in the private sector. However, the Federal Government has so far failed to provide robust reliable investments in quantum computing. The lack of investment in STEM education and research speaks to the misguided priorities of this Republican Congress. While wealthy shareholders get most of the gains from a $2 trillion Republican tax bill, Congress is under-investing in students and research institutions. We fund tax cuts for the rich at the expense of our future prosperity.

Now that Congress has passed a budget agreement, we have the chance to make some of the investments that our country so desperately needs. But instead of embracing the opportunity to advance bipartisan appropriations bills, the Republican majority plans to bring up a rescission bill to pull back funding for children's health insurance programs and other programs. And today, we will be voting on a bill to literally take food out of the mouths of families.

We need to get our priorities straight. The U.S. can be a global leader in quantum computing and other groundbreaking technologies, but only if we prioritize investment for our future over tax cuts for the wealthy.

I look forward to hearing from our panel about the promise of quantum computing. I will try my best to follow what you are telling me and the challenges that we face in developing this technology. I am especially proud to welcome Professor Diana Franklin from the University of Chicago. The University of Chicago is one of the leaders in quantum computing research, and I am eager to hear more about this work.

So thank you, chairman Latta, and I yield back.

Mr. LATTA. Well, thank you very much. The gentlelady yields back. The chairman of the full committee has not made it in yet. Is there any one on the Republican side wishing to claim his time? If not, at this time that will conclude the member's opening statements. And to get to the real meat of the issue today that we want to hear about. And I won't tell you how long ago, Madam Ranker, how long—when I took computer science in college, I probably shouldn't say this, we used punch cards and teletype machines. It was a bad Saturday morning, we went back to the computer science department, and you were expecting about that much and came back with that much, and you knew you had made a mistake. But I want to thank our witnesses for being here with us today and we are really looking forward to your testimony today.

And our witnesses will have an opportunity to make 5-minute opening statements. And our witnesses today are Dr. Matthew Putman, Founder and CEO of Nanotronics; Dr. Christopher Monroe, Chief Scientist and Founder of IonQ, and Professor of Physics at the University Maryland; Dr. Diana Franklin, Professor and Director of Computer Science at the University of Chicago; and Mr. Michael Brett, CEO of QxBranch. And so again, we appreciate you being here today. And Dr. Putman, you are recognized for 5 minutes for your opening statement. If you would just press that microphone and pull it close to you and we will get started.

STATEMENTS OF MATTHEW PUTMAN, FOUNDER AND CEO, NANOTRONICS; CHRISTOPHER MONROE, CHIEF SCIENTIST AND FOUNDER, IONQ, PROFESSOR OF PHYSICS, UNIVERSITY OF MARYLAND; DIANA FRANKLIN, PROFESSOR, UNIVERSITY OF CHICAGO; AND MICHAEL BRETT, CEO, QXBRANCH

STATEMENT OF MATTHEW PUTMAN

Mr. PUTMAN. Thank you so much, Chairman Latta, Congresswomen and Congressmen.

Nanotronics does not make quantum computers. We are the enablers of technologists and companies that with us strive to revolutionize the way information can be transformed. We have provided some of the world's largest companies and smaller entrepreneurial innovators with the tools of modern computation and imaging. We work with those that build the most advanced materials in microelectronics. Nanotronics achieved this in the only way we see feasible for the continued exponential progression of technology, which is through artificially intelligent factories.

Quantum computing not only promises to break the barriers of encryption, it also breaks some fundamental barriers to human progress. Many of our greatest achievements have been characterized in terms of competition and races. Often, a technological race appears to be a war of ideologies or of business dominance. With quantum computing, there is an even greater battle, the fight against physical scarcity.

There are three areas that we must work together on to win, not only for our nation, but for humanity, agriculture, new fertilizers can feed the increasing population of the world while maintaining diversity of crops, drug discovery by being able to simulate and produce molecules faster and with greater precision than are possible by traditional means. This will not only lead to cures for diseases, but reduce the often financially restrictive experimentation and trials that are required to make even incremental improvements and treatments.

Materials for power devices from batteries to solar cells. These have been studied for decades, but in many respects, the United States is still early on in this journey. Companies are moving with speed, and with national support, it is possible that quantum computing can soon reach an inflection point.

The race to achieve a workable quantum computer that can reduce scarcity to this level requires greater national attention than has currently been realized by either the vast majority of companies, or of the country as a whole. The steps to enabling quantum computing will need to involve, one, an effort that funds the creation of factories for new quantum chips.

A semiconductor fab for classical computers can cost as much as $20 billion. To a large extent, these fabs are not being built in the United States. We have an opportunity to acknowledge and to change this trend by leading the way in the construction of factories for this next generation of powerful computing.

Two, artificial intelligence. While quantum computing itself will increase the capabilities of artificial intelligence, the ability to design materials and software for quantum computers themselves will come through the interaction of human and computer agents.

Understanding such key elements as component design, fabrication conditions, and the number of qubits needed requires collaboration of humans and machines. The number of qubits in a quantum computer is directly related to the number of calculations. A 10 qubit quantum computer can produce 1,000 calculations, and a 30 qubit quantum computer can produce 1 billion. Millions of qubits are required to achieve the full potential of quantum computing. This exponential growth in qubit to calculations is beyond the reach of factories as they are. Without the advanced tools of AI for controlling factories, a truly useful quantum computer may not be possible.

Three, education. We need to develop the expertise required for the multidisciplinary nature of quantum computer science. It is physics, chemistry, mathematics, computer science, and application curiosity and expertise are all necessary. We cannot work in isolation. We need to embrace immigration and welcome strong talent from around the world with expertise in these areas.

When we look toward the future, we can see it as a battle of ideologies, of resources, or of technologies. Quantum computers encompass all of these to some extent. Quantum mechanics is the basis of universal behavior at the smallest scales, but affects the largest of matter. It is, therefore, not surprising that harnessing this physical property has such far-reaching implications. It is because of this, that it is important that we view it with the powerful association that it warrants, with the weight of risk in a fractured world, or of great rewards in a unified one.

As we move forward, we see how quantum computing lets us scale in ways that meet not only the needs of industry, but of our country and the world.

Thank you very much.

[The prepared statement of Mr. Putman follows:]

nanotronics

Nanotronics does not make quantum computers. We are the enablers of technologists in companies that with us strive to revolutionize the way information can be transformed. We have provided some of the world's largest companies and smaller entrepreneur innovators with the tools of modern computation and imaging. We work with those that build the most advanced materials and microelectronics. Nanotronics achieves this in the only way we see feasible for the continued exponential progression of technology, which is through artificially intelligent factories.

Quantum computing not only promises to break the barriers of encryption. It also breaks some fundamental barriers to human progress.

Many of our greatest achievements have been characterized in terms of competition, and as races. Often a technological race appears to be a war of ideologies, or of business dominance. With quantum computing, there is an even greater battle: the fight against physical scarcity.

There are three areas that we must work together on to win, not only for our nation, but for humanity:

1. Agriculture – New Fertilizers can feed the increasing population of the world, while maintaining diversity of crops.
2. Drug discovery by being able to simulate and produce molecules faster and with greater precision than are possible by traditional means. This will not only lead to cures for diseases, but reduce the often financially restrictive experimentation and trials that are required to make even incremental improvements in treatment.
3. Materials for new power devices from batteries to solar cells.

These have all been studied for decades, but in many respects the United States is still early on this journey. Companies are moving with speed, and with national support, it is possible that quantum computing can soon reach an inflection point. The race to achieve a workable quantum computer that can reduce scarcity to this level requires greater national attention than has currently been realized by either the vast majority of companies, or of our country as a whole. The steps to enabling quantum computing will need to involve:

1. An effort that funds the creation of factories for new quantum chips. A semiconductor fab for classical computers can cost as much as $20 Billion. To a large extent these fabs are not being built in the United States. We have an opportunity to acknowledge and to change this trend by leading the way in the construction of factories for this next generation of powerful computing.
2. Artificial intelligence. While quantum computing itself will increase the capabilities of artificial intelligence, the ability to design materials and software for quantum computers themselves, will come through the interaction of human and computer agents. Understanding such key elements as component design, fabrication conditions and the number of qubits needed requires a collaboration of humans and machines. The number of Qubits in a quantum Computer is directly related to the number of calculations. A 10-qubit quantum computer can produce 1000 calculations, and a 30 qubit quantum computer can produce 1Billion. Millions of Qubits are required to achieve the full potential of quantum computers. This exponential growth in qubit to calculations is beyond the reach of factories as they are. Without the advanced tools of AI for controlling factories, a truly useful Quantum computer factory may not be possible.
3. We need to develop the expertise required for the multidisciplinary nature of quantum computer science. Physics, chemistry, mathematics, computer science and application curiosity and expertise is a necessity. We cannot work in isolation. We need to embrace immigration and welcome strong talent from around the world with expertise in this area.

When we look towards the future we can see it as a battle of ideologies, of resources, or of technologies. Quantum Computing encompasses all of these to some extent. Quantum mechanics is the basis of universal behavior at the smallest of scales, but effects the largest of matter. It is therefore not surprising that harnessing this physical property has such far reaching implications. Because of this, it is important that we view it with the powerful associations that it warrants, with the weight of risk in a fractured world, or of great rewards in a unified one.

As we move forward we will see how Quantum computing lets us scale in ways that meet not only the needs of industry, but of our country and the world.

Dr. Matthew Putman

CEO, Nanotronics

05/15/2018

Mr. LATTA. Well, thank you for your testimony, this morning. And Dr. Monroe, you are recognized for 5 minutes. Thank you.

STATEMENT OF CHRISTOPHER MONROE

Mr. MONROE. Thank you for the opportunity to testify, Mr. Chairman. I am honored to be here for this committee's disrupter series on quantum computing.

I am a Quantum Physicist at the University of Maryland, and also Co-founder and Chief Scientist at IonQ, which is a startup company that aims to build and manufacture small quantum computers. I have also worked with the National Photonics Initiative, which is a collaborative alliance among industry, and academics with the interest in developing quantum technology. And I, with the National Photonics Initiative, we have promoted the idea of a National Quantum Initiative, and there is pending legislation that is coming up in the House Science Committee.

So I have about 1 minute to define what quantum computers are, and I think I can get to some of the basics. We know that information is stored in bits, zeros, or ones. The fundamental difference in quantum information is it is stored in quantum bits, or qubits, these can be both zero and one at the same time, as long as you don't look. And at the end of the day, you look, and it randomly assumes one of the values. But as long as you don't look, there is a potential for massive parallelism as you add qubits, you get exponential storage capacity. And because quantum computers only work while you are not looking, it involves quite revolutionary, and even exotic hardware to realize this. Individual atoms, that is the technology we use at IonQ, superconducting circuits that are kept at very low temperatures, other competing platforms involved that type of technology. It is very exotic stuff. And I think within the next several years, we are going to see small quantum computers with up to about 100 quantum bits. It sounds pretty small, but even with 100 quantum bits, it can, in a sense, deal with information that eclipses that of all the hard drives in the world. And on our way to a million qubits, where we can do new problems that conventional qubit computers could never tackle, we need to build the small ones first.

So in terms of quantum applications, I would say it falls roughly into three categories, there are strong overlaps. In the short term, quantum sensors can enhance sensitivity to certain measurements that could impact navigation, and it may be in a GPS-blind environment and also remote sensing.

In the medium term, quantum communication networks may allow the transmission of information that can be provably secure, because remember, quantum information only exists when nobody looks at it. If somebody looks at it, it changes. And that can make communication inherently secure.

In the long term, probably the most disruptive technology are quantum computers. And quantum computers are not just more powerful computers, they are radically different, and they may allow us to solve problems that could never, ever be solved using classical computers. These involve optimization routines that could impact logistics, economic and financial modeling, and also, the design of new materials and molecular function that could impact the health sciences and drug delivery, for instance. An even longer term, quantum computers could be used to do decryption, breaking of popular codes. So there is a security aspect to everything that quantum information touches.

Now, the challenges are pronounced in this field. There are a few issues. One involving the workforce and one involving the marketplace. The workforce issue is that universities are chock full of students and faculty that are comfortable with quantum physics, and we do research in the area, but we don't build things that can be used by somebody that doesn't want to or need to know all the details. Whereas industry makes those things, but they don't have a quantum engineering workforce.

The marketplace is also a challenge because we don't know exactly what the killer app for quantum computers, in particular, will be. So we have promoted the idea of a National Quantum Initiative that would establish several large and focused hub labs throughout the country, and other components as well, including the user access program for existing quantum computers. It is imperative that the U.S. retain its leadership in this technological frontier. As we heard from the chairman, there are concerted efforts in Europe and, in particular, China, that is spending lots of very focused investments in this field.

So, in conclusion, quantum technology is coming and the U.S. should lead in this next generation of sensors, computers and communication networks. The National Quantum Initiative provides a framework for implementing a comprehensive quantum initiative across the Federal Government.

Thank you, Mr. Chairman, members of the committee, for the opportunity to speak on quantum technology and the need for a nationally focused effort to advanced quantum information science and technology in the U.S.

[The prepared statement of Mr. Monroe follows:]

STATEMENT TO THE
U.S. COMMITTEE ON ENERGY AND COMMERCE
SUBCOMMITTEE ON DIGITAL COMMERCE AND CONSUMER PROTECTION
UNITED STATES HOUSE OF REPRESENTATIVES
Hearing on
Disruptor Series: Quantum Computing
May 18, 2018
Christopher Monroe, PhD
on behalf of the National Photonics Initiative

Thank you for the opportunity to testify, Mr. Chairman. I am honored to be here before you and the Subcommittee on Digital Commerce and Consumer Protection to offer testimony on the committee's "Disruptor Series: Quantum Computing." I am a quantum physicist and Professor at the University of Maryland, with over two decades specializing in the field of quantum information science. I am also the chief scientist and co-founder of IonQ, Inc., a startup in College Park, MD that will produce universal and re-configurable quantum computers. Over the past year I have had the opportunity to work with the National Photonics Initiative (NPI), a collaborative alliance among industry, academia and government to raise awareness of and increase investment in the fields of optics and photonics which enables much of quantum technology.

Through the collective efforts of the NPI, I have worked with experts at the University of Chicago, Duke University, Intel Corporation, IBM, Stanford University, AOSense, Inc., Harvard University, Google Inc., Harris Corporation, Massachusetts Institute of Technology, Northrop-Grumman Corporation, California Institute of Technology, University of Oregon, Rigetti Computing and the University of California, Berkeleyto develop a National Quantum Initiative (NQI). I am offering my testimony today on quantum computing and the need for our nation to create and support this NQI.

I appreciate the committee's interest to examine the potential of quantum technology. This is the second time in the past year that I have testified before Congress discussing the importance of an NQI. I was honored to testify before the House Science, Space and Technology Committee in the October 2017 and was later invited to attend the Committee's working group discussion in February on this important topic. I am pleased to keep this conversation going today as part of the Energy & Commerce's "Disruptor Series: Quantum Computing" hearing. I hope the testimony I present today will further this Committee's education about the value and importance of quantum computing and the specifics for implementing an NQI.

About Quantum Information Science

The exponential growth in the power of information technology – Moore's Law – catalyzed US productivity and economic growth over the last 50 years. But, like much of our nation's aging infrastructure, this growth is now ending as scientific breakthroughs from the 1950s and 1960s reach their technological limits. This jeopardizes the safety and security of the American people and threatens what has been the backbone of US economic growth over the past several decades.

There are many complex problems in science and society that will never be solved using conventional computers and information technology. Quantum technology (QT) can store and process otherwise inaccessible amounts of data, owing to the unique principles underlying quantum systems. Unlike the 0s and 1s in conventional computers, *quantum bits* can represent both values 0 and 1 simultaneously, taking on definite values only when observed. The power of a quantum computer doubles with each added quantum bit, leading to many potential applications that are impossible using conventional technology:

- **Optimization over huge data sets**. Quantum computers will be able to sort rapidly through data sets that are too large to ever be stored on conventional devices, such as real-time video of the entire surface of the earth. Quantum programs can potentially store, optimize, or search such databases very rapidly, with potential uses in autonomous vehicle navigation, weather prediction, machine learning, economic market analysis, code-breaking, and logistics including energy and transportation systems.
- **Design of new materials and molecular functions**. Quantum computers can be programmed to simulate the behavior of complex molecules and materials beyond the reach of conventional computers. This will usher the discovery of new substances with exotic electrical/mechanical properties, designer molecules for efficient drug activity, and efficient materials for the conversion of energy between light and electricity.
- **Secure communications.** Quantum bits change when they are observed, meaning it is possible to send information while knowing whether or not it is secret. Quantum communication can also allow secure communication between multiple (possibly untrusted) parties for optimal decision making, and for interconnecting large-scale quantum computers via a quantum internet.

- **Quantum sensing and metrology**. Quantum technologies enable a new generation of atomic clocks and ultra-precise sensors with applications ranging from natural resource exploration and biomedical diagnostics to navigation in a GPS-blind environment.

Nearly all implementations of quantum computers will use photonics in a key role for their operations. A quantum Internet will communicate data between quantum computers using pulses of light traveling on optical fibers. Quantum photonics is already used to operate the most accurate clocks on Earth and the most sensitive probes for biomedical use and geo-exploration.

A Call to Action: Advancing Quantum Technology (QT)

Because of the great promise quantum information science holds for next-generation computing and processing, there are several independent federal and industry efforts underway to advance the research and technology. For example, widespread national interest in quantum information science also coincides with a new perspective on quantum sensors and quantum computing from the Department of Energy (DOE) and recent initiatives launched by the National Science Foundation (NSF) and the National Institute of Standards and Technology (NIST).

Perhaps most importantly, the United States is not alone in pursuing quantum research and technology development. In contrast to the decentralized funding structure of quantum information science in the United States, European entities have recently established large, focused, academic/industrial thrusts including the UK Quantum Hub Network ($400 million/five years), the Netherlands QuTech Initiative ($150 million/10 years) and the European Union (EU) Flagship Quantum Program ($1.3 billion/10 years). Outside of Europe, China is aggressive in its commitment to quantum; the country recently launched a satellite devoted to quantum communication protocols, and there is report of a $10 billion investment into a quantum laboratory in Hefei, China. Major initiatives are also underway in Australia and Canada.

This explosion of activity worldwide should be a call for action in the United States. To ensure competitiveness and national security in the field of quantum information science, the United States should dedicate resources to coordinating existing federal and private programs and filling in critical gaps. Especially important are those gaps that exist between academic and government laboratories that lack systems engineering and product development expertise, and within the private industry, which lacks a trained quantum engineering workforce.

Establishing a National Quantum Initiative (NQI)

An NQI will address one of the Grand Challenges of the 21st century – harnessing quantum as a fundamentally new technology to serve national needs in information infrastructure, chemical and biomedical research and development (R&D), cybersecurity and defense capabilities. As quantum information sciences have the potential to touch nearly all areas of science and technology, its development and implementation through the NQI will naturally engage all STEM fields.

QT will also usher great scientific opportunities. Just as the LIGO gravitational wave detector enables scientists to peer into the cosmos with new eyes, QT opens windows into a realm governed by the counterintuitive laws of quantum physics. More than being the basis for new, essential technologies, QT will reveal ever deeper understanding into the nature of the physical world. QT will also advance fundamental science by providing computing power to simulate a host of intractable problems from nuclear physics and neuroscience to other complex interacting systems.

In order to help foster the implementation of an NQI, the NPI drafted an NQI Action Plan and unveiled it in early April. The Action Plan was in fact a major focus of the annual Capitol Hill Day hosted late last month by the NPI that brought NPI representatives from across the country to Capitol Hill to discuss the importance and potential of photonics-enabled quantum technology.

The Action Plan follows the June 2017 white paper, "Call for a National Quantum Initiative" produced by a collective of academics, industry experts and professional societies through the direction of the NPI. The NQI was then supported during the October 2017 hearing by the House Committee on Science, Space and Technology entitled "American Leadership in Quantum Technology," where I presented testimony on behalf of the NPI demonstrating that an NQI will ensure scientific leadership and economic and national security.

NQI Implementation Plan

The operational goals of the NQI are to (a) Engage and produce a world-leading industrial QT workforce, (b) Engineer, industrialize, and automate QT including quantum computers, communication systems and quantum sensors, (c) Provide access to the emerging quantum computer systems, (d) Develop conventional technology and intellectual property (IP) needed to support and enable QT, (e) Produce quantum software and new applications of QT, and (f) Continue the fundamental research needed to support these NQI goals, and arising from the capabilities of QT.

The NQI will be anchored by three to six new facilities called **Quantum Innovation Laboratories** (QILabs), along with a **Quantum Research Network** (QRNet) and a **Quantum Computing Access Program** (QCAP). Each QILab will be located at a central facility in the U.S. and have a distinct and focused research and development mission and may include satellite QILab participants and facilities as appropriate. The QILabs will provide sophisticated, well-engineered experimental platforms for developing and testing QT and performing state-of-the-art scientific studies. The QILabs will supplement existing technology transfer and research programs at government agencies, which will also continue to support fundamental research in quantum science necessary for QT innovation. QRNet will consist of a web of autonomous research groups distributed throughout the country at academic, government, and industrial sites. QCAP will ensure leading American researchers have access to quantum computing capabilities.

Each **QILab** and its satellites will focus on research and development of a particular family of quantum technologies, or a suite of closely related technologies, including supporting technology, control systems, software and user interfaces, and theoretical co-design of applications or algorithms mapped to the technology. For example, QILab thrusts in solid-state superconducting and semiconductor quantum systems would fabricate quantum computers with more than 100 quantum bits, develop and optimize quantum materials, advance cryogenic packaging and fast electronic control systems, and mitigate noise from material defects. QILab activity in isolated atomic systems including trapped ions and neutral atoms would develop quantum computers with more than 100 quantum bits, engineered with external optical control systems to quantum entangle and manipulate large-scale atomic systems for quantum sensors and atomic clocks. QILab technology may feature the engineering of photonic quantum networks and supporting technologies for enabling long-distance (greater than 100 km) transmission of quantum information through a quantum internet, for linking nodes of a distributed quantum computer operating with more than 100 quantum bits, and for distributed sensing applications. QILab efforts may involve quantum-enabled sensing applications including subsurface imaging, biomedical imaging, and GPS-free navigation.

The **QRNet** program will support fundamental research of QT by funding individual efforts to investigate and collaborate with QILab technologies, combine different QT for hybrid quantum systems, and uncover promising quantum systems for future quantum bit realization and QT development. QRNet will also investigate new quantum algorithms and its enabling software to drive existing QT, with potential applications in the areas of quantum chemistry and materials development, artificial intelligence and machine learning, and optimization.

The **QCAP** will support the activities of the QILab and QRNet programs by providing access to the most advanced American quantum computing systems and simulators. The most advanced commercially available American-made quantum computing systems will be made available via secure cloud access to all QILab and QRNet projects, applicable advanced scientific computing projects, and U.S. government researchers. The facilities will include technology from multiple American vendors and at least two different underlying quantum computing hardware technologies. Additionally, the QCAP should leverage high-performance computing resources to allow application developers to simulate aspects of the quantum algorithms and hardware in the QILab and QRNet programs.

Creating a Quantum Workforce

A key challenge in the development of QT in the U.S. is the workforce gap between university research efforts and industrial development. University laboratories cannot properly engineer QT, given their central mission of education and research, and lack of dedicated engineering teams. Industrial QT efforts just underway in the U.S. will produce first-generation quantum technologies. However, there is a limited engineering workforce to fabricate and test this new type of technology and a severe shortage of quantum software developers to bring quantum computers and devices to users. The transition from quantum research to usable quantum technology in the marketplace is impeded by several challenges:

- The mismatch between the quantum research community, which does not engineer or manufacture products, and the industrial engineering community, which does not have a sizable workforce with training in the quantum sciences.
- The disparity between small-company innovators and their yet-to-be developed marketplaces.
- An ecosystem of conventional technologies to support quantum devices that has not been developed because quantum technologies are not yet used in high-volume applications.
- Conventional device manufacturers typically do not have the expertise to develop products targeted at quantum systems.

The NQI will become a proving ground for academic, government, and industrial scientists and engineers to pool their resources for technology developments and to provide a QT talent pool for the future development of quantum computers, quantum communication networks, and quantum sensors.

The NQI will serve as a catalyst to spur the urgently needed quantum economy, much like early investments by government sparked the development and growth of the Internet. The overarching goal of the NQI is to remedy these gaps in capabilities and marketplaces in order to hasten the development and deployment of quantum information technology, while propelling the United States into a continued leadership role in this vital field.

Budget and Administration

The QILab, QRNet and QCAP components of NQI will be administered through the civilian agencies NSF, NIST, and DOE with an overall budget of $800 million over an initial 5-year phase. This includes a $500 million budget for the QILabs, with some funded at higher levels around $25 million per year, while others will have lower funding needs. The QRNet will be funded at $200 million, or $40 million per year, and the QCAP will be funded at a level of $100 million over five years.

Each QILab will involve additional in-kind support, including facility space, research infrastructure, and scientific and administrative personnel from the host institutions. Joint research-and-teaching programs will be provided by satellite partner universities, supported by grants from the QILabs or other mechanisms. Funds will also be made available by QILabs to support research by non-university off-site groups contributing research relevant to the QILabs goals. Industrial members of the QILabs will embed industrial researchers and engineers for termed periods, with the goal of these industrial employees returning with expertise in quantum technology. Industrial stakeholders will also provide student fellowships and internships at the QILab host universities or laboratories, with opportunities for these researchers to intern both at the QILabs and at the engaged industrial partner locations. Intellectual property invented at the QILabs will be shared among the participants, with each QILab determining an IP plan suitable for its performers. In addition, support from the Small Business Innovative Research and Small Business Technology Transfer Research programs will be directed toward supporting the Initiative.

QILabs/QRNet/QCAP will be administered and funded in a coordinated fashion by an appropriate grouping of programs within NSF, NIST, and DOE, to be decided jointly by those agencies, and informally advised by QT experts selected by NSF, NIST, DOE, and the Department of Defense (DOD) and Intelligence agencies, accounting for recommendations by industry. These agencies will coordinate their existing programs in underlying quantum science and technology with the QILabs. The QILab and QRNet performers will be selected by the above agencies based on existing solicitation and evaluation procedures. Each QILab will be led by a scientific and administrative director, who will coordinate the operation of the QILab with the above agencies.

Conclusion

The NQI Action Plan is intended to provide a framework for implementing a comprehensive quantum initiative across the federal government. It will require significant investments in research and infrastructure but at the same, holds tremendous promise for solving some of our most pressing communications and security challenges.

These investments will put the U.S. in a position of global leadership in terms of quantum information technology development, economic growth and advanced research in areas ranging from health to national security. In order to realize these goals in the future, we must make investments and commitments today.

I – along with the consortium of leaders from industry and academia that signed onto the NQI Action Plan and who have extensive knowledge in information technology and quantum science and technology – will continue to be available to this Committee and others as they work to draft comprehensive quantum legislation.

I thank you, Mr. Chairman and members of the Committee, for the opportunity to speak on quantum computing and the need for a nationally focused effort to advance quantum information science in the United States.

Mr. LATTA. Well, thank you very much.
And Dr. Franklin, you are recognized for 5 minutes.

STATEMENT OF DIANA FRANKLIN

Ms. FRANKLIN. Thank you for the opportunity to testify, Mr. Chairman, and Ranking Member Schakowsky. I am honored to be here before you in the committee to offer testimony on the promise of quantum technology. The important role universities must play to realize commercialization, and the biggest challenges we are facing in doing so. In my dual roles as Director of Computer Science Education at UChicago STEM Ed, and a Research Associate Professor in the Department of Computer Science at the University of Chicago. I research emerging technologies and computer science education.

As lead investigator for quantum education for the EPIC quantum computing project in the NSF expeditions in computing program, it is my mission to design and implement educational initiatives at K–12, university and professional venues to develop a quantum computing workforce.

Quantum computing can be a game changer in promising areas, including drug design and food production. By accelerating research time to develop drugs, critical Federal research in Medicaid dollars could be saved, along with improved quality of life.

Unlocking the secrets of nitrogen fixation through quantum simulation could vastly reduce the energy costs of fertilizer production, and thus food production throughout the world. While the university has historically been on the forefront of computer science and emerging technologies, lapses in academic funding for quantum computer science have allowed global competitors to make great strides. Putting the U.S. back 10 years from where it could have been in research output and workforce development.

In the past 17 years, since the inception of quantum computer science, distinguished from quantum physics and algorithm development, academic funding has only been available for 8 of these years, leading to only 10 Ph.D. students being trained, rather than a potential of almost 200 students, and no meaningful education programs aimed at this area.

As research groups came and went with the funding, post-docs were laid off and graduate students were transitioned to conventional computer science fields. Yet, universities are critical to commercialization. While companies work individually and compete against each other to produce proprietary tools, academics produce results and tools that all companies can use and improve upon, as well as trained experts who can work at companies. They are both necessary for the commercialization of quantum computing.

The challenge of bringing quantum computers to the point of usefulness cannot be underestimated, both in building reliable machines and writing software. Professor Christopher Monroe knows extensive expertise in the former. I am here to talk about the increasingly important role that computer scientists must take. Historical funding and theoretical software and quantum devices has created a chasm between the software, which assumes large, perfect hardware, and real hardware that is small and unreliable at this point.

NSF has recently recognized this issue supplementing their hardware initiative quantumly with a stat program that requires an interdisciplinary team that works to bridge this gap. One gap is in software development. There is a difference between a quantum algorithm and software that can solve a particular problem. Bridging this gap requires interdisciplinary teams such as exists at QxBranch. Deep expertise is necessary to figure out how to modify software that works in one specific context to another, much more so in quantum computing than in traditional computing. If this were furniture construction, what we have right now is piles of wood, screws and nails. An expert needs to figure out how to use those to create useful furniture. Instead, what we want in the future is for nonexperts to be able to go to quantum Ikea, get a prefabbed kit and easily modify it for their application. This exists for classical computing, but not for quantum computing.

Another gap is between software and hardware. Current algorithms are written for perfect hardware, but hardware on the horizon is very error prone. We are on a journey to that perfect hardware, but we are not there yet. It is like if you meticulously planned to prepare a gourmet meal for ten, but when you arrived, there were only supplies for six, and you could only use the kitchen for 2 hours prior to the meal, you would need to adjust your plans. Current and quantum computers that are on the horizon can only sustain computations for a limited time, and they are very small. Some modifications can be automated. However, for more advanced modifications, the plan needs to be rethought, thus, some of the specific hardware limitations, like the specific ways in which different technologies tend to introduce errors, need to be communicated to the programmers so they can figure out how to adjust their applications.

In order to realize quantum computing, Federal funding needs to be, first and foremost, consistent, directed at not just building hardware and developing algorithms, but to interdisciplinary teams that include applications developer and computer scientists. Spread across a range of agencies with different missions like NSF, DARPA, DOE, and DOD, directed not just at technology development, but to workforce development, so there are more people available to write applications and to perform the engineering work at these companies. And above all, supporting the K–12 STEM pipeline to train the next generation of innovators.

With a significant investment in hardware, software, and workforce development, I am confident the United States can maintain its dominance in computing.

This concludes my remarks. I appreciate this opportunity to speak with subcommittee members. And I am happy to answer any questions you might have.

[The prepared statement of Ms. Franklin follows:]

Testimony of Diana Franklin, Ph.D.
Director of Computer Science Education, UChicago STEM Education
Research Associate Professor, Department of Computer Science
University of Chicago

Before the Subcommittee on Digital Commerce and Consumer Protection
For the Committee on Energy and Commerce
May 18th, 2018

Summary

Quantum computing holds great promise in solving compelling problems facing society today including drug design to food production. While the United States is on the forefront of many technologies, gaps in funding have left the U.S. scrambling to stay ahead in quantum computing. Major well-funded initiatives have been announced in Europe and China. Gaps in funding in the U.S. have significantly reduced the number of qualified quantum computing experts available for companies to hire to design and build quantum applications and hardware.

Much of historical funding has focused on two efforts: algorithm development and quantum device development. As a result, several (but not many) algorithms have been developed, all of which assume a perfect machine with abundant qubits that hold their values for a significant amount of time. This has left two major gaps that quantum computer science needs to fill.

First, there is a gap between usable quantum applications and theoretical quantum algorithms. The federal government needs to fund researchers to better understand how to bridge that gap, educators and researchers to create instructional materials to teach people how to create applications even without full understanding of quantum hardware, and educators use those to train computer scientists.

Second, there is a gap between the assumptions current applications make about the size of the computer and length of time it can operate that make near-term computers fall short of the promise to compute faster than traditional computers. The federal government needs to fund quantum computer science research groups to develop the knowledge and tools to both automatically optimize programs for real hardware constraints and expose particular details to programmers that might affect how they write their programs.

Finally, we must look beyond the current challenges and fund the K-12 STEM Pipeline to sustain our nation's long-term global competitiveness.

Full Testimony

Thank you for the opportunity to testify, Mr. Chairman and the ranking member. I am honored to be here before you and the Committee to offer testimony on the potential for commercially-available quantum computers and America's global competitiveness in Quantum Technology. For your background, my research is in computer science and computer science education. I am also the Director of Computer Science Education at UChicago STEM Education and a Research Associate Professor in the Department of Computer Science at the University of Chicago. I began working in quantum computer science in 2000, but, as I will discuss later, my participation has reflected the inconsistent academic funding in that area.

I am testifying today on behalf of the University of Chicago, UChicago STEM Education, and the EPICQ quantum computing project, a multi-institution collaboration between the University of Chicago, MIT, Princeton, Duke, and UC Santa Barbara. The goal of the project is to bridge the gap between the perfect machines that applications need and the error-prone machines that are on the horizon. As the lead investigator for quantum education for the EPiQC quantum computing project in the NSF Expeditions in Computing Program (NSF's largest single-project investments), it is my mission to provide education and awareness at all levels of the educational pipeline so that we can train a robust workforce to develop and utilize these machines.

Promise of quantum

Quantum computing holds great promise for several commercial applications.

One promising area is in drug design. As the baby boomer generation ages, the incidence of Alzheimer's is predicted to increase from 1.5% to 50% in 2050. Medicaid spending on Alzheimer's is projected to rise from less than 5% of the 2020 budget to nearly 25% in 2040 (Bredfeldt, 2015). In the past two years, J&J, Merck, Pfizer, and Eli Lilly have cancelled their Alzheimer's drug trials, a disappointing end of a long, expensive road that consumed significant federal research funds. Quantum computing may someday provide simulation accuracy to predict whether these drugs would reduce the accumulation of amyloid plaque, allowing emphasis on the deeper question of whether removing this plaque buildup slows or reverses cognitive impairment. Thus, quantum computing would have allowed either a success in one of these drugs or a quicker pivot to alternative approaches.

A second promising area is in fertilizer production, through better understanding the biological nitrogen fixation by the enzyme nitrogenase. The current industrial HaberBosch catalyst requires high temperatures and pressures and is therefore energy intensive (Reiher, et al). Unlocking the secrets of this process through quantum simulation could vastly reduce the energy costs of food production throughout the world.

Global Competitiveness

While the United States has historically been on the forefront of computer science, computer systems, and emerging technologies, lapses in public funding for quantum computing have allowed global competitors to make great strides. International initiatives include the European Union (EU) Flagship Quantum Program ($1.3 billion / 10 years), the UK Quantum Hub Network ($400 million / five years), and the Netherlands QuTech Initiative ($150 million / 10 years). China is building a new $11.9 billion quantum computing research facility in Hefei. On the commercial front, Chinese companies Baidu, Alibaba, and Tencent Holdings have announced major initiatives in Quantum Computing. In February, Alibaba became the second company worldwide, behind IBM, to announce a more than 10-qubit cloud quantum computer.

Why isn't the United States farther ahead? To answer that, we need to look at historical funding trends. Academic institutions play a central role in the development of commercial quantum computers, a role previously played in many key technologies, as conceived by Vannevar Bush after World War II. They make research strides that develop ideas to the point where they become commercially viable, a point now reached for quantum computing. Research groups provide tools that all companies, not just one, can benefit from. Finally, universities create a workforce of bachelor's, master's, and PhD-level experts to contribute to those commercial efforts. Quantum computer science, our research area, explores optimizations necessary to make quantum hardware usable to software. Our most recent PhD graduate had job offers from four companies.

Had funding been consistent over the past 17 years since the inception of quantum computer science, approximately 200 PhD students, and many more MS and BS students, could have been produced. However, only 8 of those 17 years have been funded, wreaking havoc on both the research progress and the graduate student training pipeline, and resulting in only 10 PhD students, and undergraduate programs are only now being created. The DARPA QUIST program first recognized that device-level progress was not sufficient - progress needed to be made in how to create a system of many qubits working together. In 2001, the first quantum computing science project, QARC, was funded. However, when the first round of funding expired in 2006, the next five years of funding was only open to classified projects. In 2011, IARPA awarded 5-year grants. Just over a year into it, the grant was cancelled, just as collaborating groups had hired post-docs and accepted graduate students. Most let go their postdocs and transitioned their graduate students to traditional computer science subjects. Through this journey, research groups came and went as group leaders chose not to expose themselves or their students to this level of uncertainty. Now, few senior students are in the pipeline to feed companies developing quantum computers. Developing this pipeline of students, or retraining existing professionals, is critical the success of commercial quantum computers.

Challenges

Quantum computing harnesses the quantum physics properties of fundamental particles, operating on them to perform useful work. However, the scale of the challenge in bringing these computers to the point of usefulness cannot be underestimated. These challenges can largely be split into two areas - building stable machines that protect quantum bits long enough for the calculations to complete and writing software to take advantage of the quantum state in ways that provide exponential advantage over current machines.

My esteemed colleague and co-panelist Prof. Christopher Monroe can talk to you about the physical challenges present in creating stable machines. I am here to talk about the increasingly important role that computer scientists need to take to make these computers perform useful work.

Much of historical funding has focused on two efforts: algorithm development and quantum device development. As a result, several (but not many) algorithms have been developed, all of which assume a perfect machine with abundant qubits that hold their values for a significant amount of time. At the same time, great strides have been made in devices. 50-qubit machines have been built that perform computation. However, they do not yet perform useful computation. That is, a quantum computer is currently no more powerful than an 80's desktop.

We ask ourselves - What is necessary to implement a known algorithm to model nitrogen fixation for improving fertilizer production? Next, what is necessary to modify an algorithm to write an application that will simulate potential drugs for Alzheimer's on a quantum computer in order to shorten development time? First, we need resources and workforce training to develop more algorithms and understand how to apply those algorithms to new situations. Second, we need knowledge and tools to better tailor algorithms to the limitations imposed by emerging quantum hardware.

Applications-Algorithms Gap

The relationship between an algorithm and an application is a bit like the relationship between a screw and a house. The architects and builders need to understand when to use a screw or nail and how to use them, but that knowledge alone does not build a house. They also need to place the wood and drywall in the right places so the screws and nails can do their jobs and result in a useful structure. You can not build software with algorithms alone - you need to understand how to apply them to real problems.

In traditional computing, years have been spent designing algorithms, learning how to express and reason about their properties, teaching aspiring computer scientists how to choose between algorithms and how to use them in real-world problems. Quantum algorithms are a long way from being ready for this level of teaching. Theorists know how to express and reason about their properties. However, making the leap to use is a large gap that must be filled. Quantum algorithms are expressed at a hardware level, requiring intimate knowledge of qubits. In traditional computing, application developers no longer need to understand what happens at the binary / bit level - programming languages and software libraries have been developed that allow programmers to think at a much higher level, and that has led to substantial reduction in the amount of time it takes programmers to write code. It is akin to the difference between Home Depot and IKEA - do you want to provide only basic building materials or make some partially-fabricated kits?

Algorithms-Hardware Gap
There is a huge gap between the stability hardware provides (and will in the near future) and the stability algorithms assume. In conventional computing, hardware has been stable for decades, and instability has only occurred recently with the seemingly relentless shrinking of transistors through Moore's Law. Still, low-cost error-correction techniques can protect most operations and memory. Not so for Quantum Computing.

What would happen if you had planned to prepare a gourmet meal for 10, but when you arrived, there were only supplies for 6, and you could only use the kitchen for two hours prior to the meal? You would need to adjust your plans. Current quantum computers can only sustain computations for a limited time, and they are very small. Some modifications can be automated - each person will get smaller portions. Changes like this can be automated. However, for more advanced modifications like shortages of specific ingredients, the plan needs to be rethought. This requires the algorithm designer to create a modified algorithm.

Recommendations

In order to realize quantum computing, the federal government needs a funding initiative aimed at filling these gaps. Tools and educational materials must be developed for the computing side of quantum computing. Without these, we will have machines with little useful software to run on them. It is only through an interdisciplinary effort between hardware designers, experts in target application areas, and computer scientists, that we can tackle these challenges. If this work is done in the public domain, then all businesses will benefit from the resulting tools and expertise.

Tools:

Software Infrastructure: Automated tools that optimize code for limited, unstable hardware.

Error-Aware Algorithms: Expose and education algorithms developers about specific details of errors in the hardware for which there are no automatic optimizations. Collaboratively create strategies for modifying algorithms given specific error patterns in different device technologies.

Languages or Software Libraries: Tools that allow quantum software developers to program quantum algorithms with incomplete understanding of qubits and the operations that directly affect them.

Workforce Development:

Quantum Algorithms in CS: Graduate-level applied quantum algorithms instructional materials that goes beyond the characteristics of quantum algorithms to focus on how to use them in real-world applications. Highly trained individuals could go on to work in interdisciplinary teams with non-computer scientists to write applications or write languages or software libraries to abstract quantum-level details of algorithms away from application implementers.

Quantum Applications beyond CS: Graduate-level instructional materials co-designed by application area experts and quantum computing experts that would teach students what types of problems can be solved using quantum computing and to modify one application for a different problem, given an existing application and languages developed above. Individuals would work closely with computer scientists trained in quantum algorithms to create new quantum applications.

Quantum Computer Science Course: Graduate-level instructional materials that relate quantum computing systems to conventional systems, providing training or retraining to students who already know how to build conventional systems. They would develop the software infrastructure tools above and work at quantum computing companies.

STEM Pipeline: We need to mobilize now to train the innovators of tomorrow. Pushing forward quantum computing requires deep expertise in computer science and physics, and in order to widen our pool of talent, we must support the CSforAll movement to make computer science an integral part of K-12 education. Robust programming skills are increasingly important in not only all STEM fields, but economics, finance, and increasingly liberal arts fields. Early, positive exposure to computer science enlarges the talent pool by attracting individuals who would not otherwise consider such careers.

Conclusion

With a significant investment in hardware, software, and workforce development, I am confident the United States can maintain its dominance in computing and quantum computing. This concludes my remarks. I appreciate this opportunity to speak with Subcommittee members, and I am happy to answer any questions you might have.

Bredfeldt, C., Rice, K., Alecxih, L. The projected impact of the baby boomers on the trajectory of and spending on Alzheimer's disease Alzheimer's & Dementia: The Journal of the Alzheimer's Association , July 2015, Volume 11 , Issue 7 , P618

Reiher, M., Wiebe, N., Svore, K., Wecker, D. and Trover, M. Elucidating Reaction Mechanisms on Quantum Computers, Proceedings of the National Academy of Sciences, 2017.

Mr. LATTA. Thank you very much.

And Mr. Brett, you are recognized for 5 minutes. Thank you.

STATEMENT OF MICHAEL BRETT

Mr. BRETT. Thank you, Chairman Latta and Ranking Member Schakowsky, and members of this committee. I am thrilled to be here today to participate in today's hearing and discuss the opportunities and challenges presented by quantum computing.

My name is Michael Brett. I am the CEO of a company called QxBranch. We are an advanced data analytics company based here in Washington, D.C., also with teams in Australia and the U.K. We are a fast-growing team of data scientists, software engineers, and machine learning specialists who design algorithms for challenging data problems. We are at the cutting edge of creating algorithms that find patterns, detect anomalies, and uncover other business insights that help our customers reduce their costs and to serve their customers better.

Data analytics is already a rapidly advancing technology area delivering benefits to people all over the world, but we are particularly excited about what quantum computing can do for our business. As we have heard, quantum computers are not just a faster computer, they enable an entirely different approach to performing calculations. In the realm of quantum physics, there is some incredible and surprising phenomena that, if harnessed, could allow us to solve some interesting and practically unsolvable problems, like simulating the interaction between molecules. As these molecules grow in size, the computational costs grows exponentially larger.

Our friends who build quantum computing hardware are in the process of creating machines that take advantage of these unique phenomena. And you heard a great example from Chris Monroe this morning at IonQ. These machines allows us as software developers to solve difficult problems using a different kind of mathematics, quantum math, much more efficiently than we ever could on classical computers. And our ambition is simple: Quantum computers will allow us to solve some of the most intractable and most valuable computational problems that exist today.

These new quantum solutions will benefit Americans in ways they might not ever be aware of. Globally, the race is on to apply quantum computing to problems in transport, energy production, health science and pharmacology, finance and insurance, defense and national security. And we want our applications to be the first apps in a quantum apps store.

Looking forward to the kind of quantum computers that are likely to become commercially available over the next decade, there are broadly three classes of application that have become possible in the near term. The first are optimization problems, like logistics and transport routing, financial portfolio optimization. The second is in machine learning, where we can accelerate some of the most computationally expensive parts of training and artificial intelligence, to detect patterns in large and complex data sets.

And the third is in chemical simulation, where we can use a quantum computer to simulate the behavior of molecules and materials, and design new processes around them. Across these three applications, the potential value to everyday citizens is immense. Now let me give you a concrete example of where this could apply. QxBranch recently completed a study into quantum computing applications with Merck, the pharmaceutical company. We worked together to design a quantum algorithm and test it on today's available hardware, to look at an approach to optimizing the production of a particular drug. And the particular drug that they are interested in has an extremely challenging production optimization process involved. And quantum computing gave us the tools to look at the manufacturing process in an entirely different way that could radically change the efficiency of creating this drug and delivering value to the consumer. It is applications such as this that we are focused on at QxBranch, breakthroughs enabled by a new approach in computing that allows us to change the way we think about business and manufacturing processes. There are some challenges ahead, though, in realizing this technology, and the Federal Government can help us create the environment for industry to lead.

The three biggest challenges I would like to highlight today, first the skills and workforce. As we have heard, if we are to be successful at bringing quantum computing to market we need a highly skilled, multidisciplinary, diverse workforce with core skills in quantum information science, computer science, data analytics, machine learning and AI, combined with germane expertise in finance, pharmaceuticals, energy and other industries. And we need American universities to send us graduates with these skills.

The second is in international cooperation. As American companies compete in this emerging ecosystem, we will achieve our fullest success through international cooperation. There is valuable scientific research and engineering development that is being made elsewhere, including in key allies such as Australia, the U.K., Canada, Japan, and Singapore. We need to be able to access the best talent and technology globally and this means partnering.

There will be national security considerations for this technology, of course, but if export restrictions are applied prematurely or without your consideration, it will stifle commercial innovation.

Finally, we need to maximize and leverage private sector investment into this technology area. Over the past 18 months, we have seen an incredible acceleration in corporate R&D and venture capital flying into this technology. It is an exciting time, but I must stress that we are just at the beginning of this technology development. And the government can maximize and leverage this investment through targeted Federal funding and coordination to reduce the gaps and overlaps in R&D and help accelerate technology.

So in closing, I would like to reiterate my appreciation for the opportunity to join you today and share a little about what we are doing at QxBranch and quantum computing. This subcommittee is addressing important issues that will help bring quantum computing to commercial reality and give us a powerful, new tool to create valuable software.

[The prepared statement of Mr. Brett follows:]

Testimony of Mr Michael Brett

Chief Executive Officer
QxBranch, Inc.

May 18, 2018

House Subcommittee on Digital Commerce and Consumer Protection

"Disrupter Series: Quantum Computing"

2322 Rayburn House Office Building

Chairman Latta, Ranking Member Schakowsky, Members of this Subcommittee,

Thank you for the invitation to participate in today's hearing to discuss the opportunities and challenges presented by this incredible technology, quantum computing.

My name is Michael Brett. I am the CEO of QxBranch, an advanced data analytics company based here in Washington DC, with teams in Australia and the United Kingdom.

QxBranch is an advanced data analytics company we started about four years ago. We are a fast-growing team of data scientists, software engineers and machine learning specialists who design algorithms for challenging data problems.

We are at the cutting edge of creating algorithms that find patterns, detect anomalies and uncover other business insights that help our customers reduce costs, improve their understanding of risk, and serve their customers better.

Data analytics is already a rapidly-advancing technology area delivering benefits to people all over the world, and we're particularly excited about what quantum computing can contribute to our business.

Quantum computers are not just a faster computer. They enable an entirely different approach to performing calculations – an approach that asks the question, what if we go beyond limit of "classical" computers and into the subatomic, or quantum realm, to perform computational work? It turns out that this is possible, and there are some incredible and surprising phenomena like superposition and entanglement that allow us to solve some interesting - and practically unsolvable - problems like simulating the interactions among molecules as the grow in size, since the exhibit exponential growth in complexity.

Our friends who build quantum computing hardware are in the process of creating machines that allow us to take advantage of these unique phenomena. You will hear a great example of this from Dr Chris Monroe at IonQ, next. These machines allow software developers like us to solve difficult problems using a different kind of mathematics – quantum math – much more efficiently than we ever could using classical computers.

At QxBranch we are harnessing this new approach to computing to create algorithms and applications we couldn't create with today's computers. Even with all the advanced cloud and high-performance computing available to us, there are still problems that are practically impossible to solve.

Our ambition is simple – quantum computers will allow us to solve some of the most intractable and most valuable computational problems around today. These new quantum solutions will benefit Americans in ways they may not even be aware. Globally, the race is on to apply quantum computing to problems of transport, energy production, health science, pharmacology and chemistry, finance and insurance, defense and national security.

As an example, major financial institutions currently calculate their risk position, or value at risk, once a day, usually by running time-consuming and expensive processes overnight to understand the balance sheet. What if we could do this faster than once a day? How would the way we understand risk and manage financial position change if we could solve every hour, or every minute? Quantum computing may give us a new tool in the toolbox to enable domestic financial institutions to not only improve business processes to the benefit of shareholders, but also help protect and advance the financial interests of Americans in the competitive global marketplace.

Quantum computing will manifest in the cloud. Today, QxBranch already uses a mixed-compute environment to solve problems. Meaning we use multiple different types of computers to solve different problems, because different classes of processor are suited to solving different algorithms.

Quantum computing is a new, specialist processor that will be become accessible through commercial cloud platforms like those operated by Amazon, Google and Microsoft. You will not have one in your pocket, but you will access one from your pocket. Quantum computers won't replace classical computers. Rather, they will be used together with classical computers to accelerate tough, valuable applications.

And we want our applications to be the first apps in a "quantum app" store.

Looking forward to the first kinds of quantum computers that are likely to be commercially available over the next decade, there are broadly three classes of application that become possible in the near-term:

1. Optimization problems – like transport and logistics routing, production streamlining, and financial portfolio optimization;

2. Machine learning – accelerating the most computationally expensive part of training artificial intelligence systems to detect patterns in large and complex data; and

3. Chemical simulation – using a quantum computer to simulate the behavior of molecules and materials, a quantum process that is extremely challenging to simulate using classical computers.

Across these three applications, the potential value to everyday citizens is immense. Let me give you a concrete example of where this could apply:

QxBranch recently completed a study into quantum computing applications with Merck, the major pharmaceutical company. We worked together to design a quantum algorithm and test it on today's hardware that may reduce the costs involved in producing a particular drug. Merck faces an extremely challenging production optimization problem for this drug and quantum computing gave us the tools to look at the manufacturing process in a very different way with the potential to deliver significant savings to the consumer. It is applications such as this that we are focused on at QxBranch - breakthroughs enabled by a new approach to computing to that change the way we think about current intellectual, business and manufacturing processes.

There are some challenges ahead in realizing this technology, and the federal government can help create the environment for industry to lead.

The three biggest challenges I'd like to highlight today are:

1. Skills and workforce. If we are to be successful at bringing quantum computing to market, we need a highly-skilled, multi-disciplinary, diverse workforce. A team with core skills in quantum information science, computer science, data analytics, machine learning and artificial intelligence, combined with domain expertise in industrial areas like finance, pharmaceuticals and energy. We need American universities to send us more graduates with these skills.

2. International cooperation. As American companies compete in the emerging quantum computing ecosystem, they will achieve their fullest success through international cooperation. Valuable scientific research and engineering development has been made elsewhere, including key allies like Australia, the United Kingdom, Canada, Japan and Singapore. We need to be able to access the best talent and technology globally, and that means partnering. There will be national security considerations for this technology, but if export restrictions are applied prematurely or without due consideration it will stifle commercial innovation.

3. Maximizing and leveraging private-sector investment. Over the past 18 months, we have seen an incredible acceleration of private sector investment into quantum computing from corporate R&D and venture capital. This is an exciting time, but I stress that we are just at the beginning and there is a tremendous amount of hard science that is yet to be done. The government can maximize and leverage private-sector investment through targeted funding and coordination to reduce gaps and overlaps in the R&D and help accelerate the technology.

In closing, I want to reiterate my appreciation for the opportunity to join you today. The subcommittee is addressing important issues that will help bring quantum computers to commercial reality, giving us a powerful new tool to deliver valuable solutions in transport, health, and energy. Leadership in this area will not only impact American business and competitiveness in an important technology, but they also have the potential to benefit every person in our country, as innovation benefits us all.

Mr. LATTA. Thank you for your testimony. I appreciate all your testimony this morning, and that will conclude our witnesses' testimony this morning, and we will begin our questioning from the members. And I will now open with questions with 5 minutes. And pardon my allergies this morning, it is this time of year in Washington.

First, I really appreciated reading your testimony last night, and a lot of questions in 5 minutes. But if I could start, Dr. Putman, with you, if I may, because I really was interested, so what impact does quantum computer have on manufacturing in the United States? Because, like, in my district, I have a unique district, I have 60,000 manufacturing jobs, and I also have the largest farm income producing district in the State of Ohio. And in your opening statement, you had mentioned about on the manufacturing side, you talked about with drugs and agriculture, energy, and this committee deals a lot with all that, and not really on the agricultural side, but I was really interested in that. And I would like to know, especially what the impact would be on manufacturing? And also, am I correct that it would both create new opportunities while disrupting those existing industries that are out there today?

Mr. PUTMAN. Thank you, Chairman Latta, my fellow Ohioan. This is, of course, extremely personal to me as well, being from Ohio and creating and trying to enable manufacturing work. What is important, I think, about your question, is that these are brand new industries. It is not just about disrupting current industries, it has been creating jobs that are for the next generation of technologies. And this is building, I think, interesting jobs as well for technologists of the future, and that goes through entire large factories. I mentioned the cost of a fab. It is not just the cost of building a fab, we would like to bring down the cost to build fabs. It is the opportunity for workers to be working with the latest of technologies. I think that the Midwest and the rest of the country as a whole can only benefit from this.

Mr. LATTA. Thank you.

Dr. Monroe, what changes would be needed to ensure America has that workforce that is ready for quantum computing revolution? You will be hearing from the witnesses, we have to have that workforce out there in the training. So how do we get to that point? Do we need on the educational side, especially at the university levels, do we need universities that would specialize that in the field or what do we need to do?

Mr. MONROE. Well, thank you for the question, Chairman Latta. There are a number of things that we can do as a country to foster this gap, this connection between university and government laboratory research and I said, industrial production. At the university side, I am sorry to say that most engineering and computer science departments haven't really embraced this field as Dr. Franklin mentioned.

Mr. LATTA. Why? Why not?

Mr. MONROE. Well, I have my own thoughts on that. Actually my daughter is a computer science major at University of Maryland. And the computer science departments—the students are keen to get a high-paying job right after they graduate. Quantum computing, not that it is not a high paying job, but it is a very speculative field. And it is hard to identify exactly what the marketplace is. And I think—computer science departments and engineering departments, I think, they have not embraced this field as much as the sciences have. And I think that is changing at some places. My university, the University of Maryland is one of those, Chicago is another. There are several across the country that have done that, but it is not widespread. Many of these departments won't hire faculty that are doing research in this field. And I think Dr. Franklin mentioned the National Science Foundation is taking an active role in trying to change that by instituting new grant programs that foster the development of quantum computer science for instance.

So that is on the university side. On the industry side, it is a tough nut to crack, because this new technology as I mentioned involves very exotic type hardware that industry doesn't have so much experience with. And it reminds me of, in history in the 1950s, when semiconductor devices were being developed and scaled, the people who did this over the many decades that gave rise to Moore's law including Gordon Moore, who founded who Intel, these were not vacuum tube engineers who had instituted the previous generation of computers. So it takes time, and it takes risk, and it takes funding from these corporations to do that.

Mr. LATTA. Well, thank you very much. And my time is about to expire, so I am going to yield back and recognize the gentlelady from Illinois, the ranking member of the subcommittee, for 5 minutes.

Ms. SCHAKOWSKY. I am starting to understand the much-used phrase taking a quantum leap, because really what you are talking about is of all the things that I think we have heard about the most disruptive, in a good way, and in a challenging way to the future. And so, I wanted to talk to Dr. Franklin about things I think I know more about, which is about education. And I do want to hear more about EPIC and the things that you are doing.

But first, I want to hear about your efforts with younger students in a minute, but I want to first hear about what is happening at the graduate and undergraduate level. What I am hearing really from all of you is that workforce capacity is really a challenging issue. And if we are going to be competitive, and if we are going to keep up with countries that are making the EU and also China, then we need to get serious about making these public investments. But I am wondering if you can talk to me a little bit about the urgent need?

Ms. FRANKLIN. Yes. So I think Dr. Monroe mentioned that computer science hasn't had as much quantum in it. And I think it all comes back to those funding lapses, because our group and other groups started and the way courses get created is that graduate students get trained in a field, they go out and become professors, create classes and train more students. Those students need to be able to have jobs in order to make it worth it for them to take those courses. If no Federal funding—if a program gets canceled and you are two of six, and all of the Federal funding goes away, and then graduate students get put in other fields, you are not going to have an education program, and so that is what happened twice is that the Federal funding went completely away for the computer science portion of quantum computing. And so, groups that were active in getting into the field left the field.

And so now, with this new stack funding and the new EPIC program that we have, and we are planning educational initiatives at all levels, including tutorials for professionals, we have a tutorial in June and a tutorial in October for professors and graduate students who are already in the field who want to transition to quantum computing. There is an initiative in the institute for molecular engineering at UChicago that has an undergraduate degree with a quantum track. We are partnering with them to create some computer science to add to that hardware track. And there is a program——

Ms. SCHAKOWSKY. Is that the quantum engineering degree that you are talking about?

Ms. FRANKLIN. Yes. There is a quantum track of the molecular engineering degree, yes. And they also have a program to embed graduate students that are working in all areas of quantum with with companies. And so, we are participating in that. So we are trying to train other research groups so that they can start doing research in quantum.

Ms. SCHAKOWSKY. Given the potential, it seems to me that we have to have some sort of almost like a moonshot mentality about investment. And you are so right about all kinds of research. If it is not steady and consistent, then we either have a brain drain, people go elsewhere, or that research app grinds a halt.

But do tell me a bit about some of the things you are working on in the primary and high school level. That is also under your bailiwick, too, right?

Ms. FRANKLIN. Right. So at the elementary and middle school level, we are looking at not doing quantum computing per se, but computer science in general, because in order to have a quantum computer scientist, you need a computer scientist first. And so efforts like CSforALL are critical in getting computer science early because in science, anyway, if a student isn't thinking about becoming a scientist by sixth grade, they are statistically very unlikely to become a scientist. And so we believe the same thing may be true for computer science. So we want to have those initiatives early.

On the physics side, we are looking at what are the aspects of quantum computing that are unintuitive when you get there? And one of them is this idea of measurement, Chris Monroe said that all the operations work fine until you look at them. And it is an issue that the measurement device actually perturbs the state. For example, if you had Matchbox cars and you wanted to see how fast they were going, you could put your hand out and feel how hard it hits your hand. But now that stopped the car. And so this idea that your choice of measurement actually affects the system. And in quantum computing you have no other choices. For a car you could video it and then calculate which one was faster, but we don't have that opportunity in quantum computing. And so those sorts of things that are very unintuitive can become intuitive if you just give the right examples at young ages.

Ms. SCHAKOWSKY. Thank you. I am pretty much out of time. I yield back.

Mr. LATTA. Thank you. The gentlelady yields lack.

The chair now recognizes the gentleman from Illinois, the vice chairman of the subcommittee, for 5 minutes.

Mr. KINZINGER. Well, I thank the chairman for yielding. Thank you all for being here. I can understand about 50 percent of the things you say, so.

Mr. Brett, in your testimony you stated that quantum computers will allow us to solve some of the most intractable and valuable computational problems that exist. Can you explain how doing so will benefit everyday Americans?

Mr. BRETT. Thank you, Congressman. There are some problems in computer science that as we add more variables to them, or more factors to them, become exponentially more difficult to solve. And so that means that the time that is required to solve that problem doubles every time we add a new variable to it. And so, we can reach a limit of our computational capacity to solve those kinds of problems very, very quickly, even with circuit computers and cloud computing that is available today.

So for everyday Americans that are problems like how do we optimize our financial portfolio in our 401(k) where the amount of computational work that is required to do that is already immense. But if we want to include more factors involved in that and get the most efficiency for our portfolio, the scale of computational challenge increases exponentially and so quantum computing can help with that. We can take on more complex and more difficult problems and solve them in a much shorter time with a new type of machine.

Mr. KINZINGER. OK. Now I am going to be honest Dr. Putman, I really don't know what I am going to say here, so I am going to say it and hopefully you understand the question. OK.

When you measure a qubit, it immediately changes its value to either a solid one or zero. So as I understand, which I don't, to manipulate a quantum computer, the operator needs to be able to make measurements indirectly without a qubit observing you doing so. How do you do that? And how does that match the capabilities of classic electronic computers and processors with billions of transistors?

Mr. PUTMAN. This is one I feel like I should have one of the quantum computing experts answer. This is something that occurs in physics that has been measured for many, many years. So how it is implemented becomes our greatest challenge, and there are several different ways to do it. Generally, you want to be in a situation where you control the atmosphere. While it is observable in nature, it is not as controllable as dealing with information series stringing of zeros and ones which just adds up in sums. I think I would like to have someone else explain the actual technology of how it might work. Dr. Monroe?

Mr. MONROE. Sure. First I would like to add that you are in good company because Albert Einstein never accepted quantum mechanics. He didn't think it was complete.

Mr. KINZINGER. So I am basically like Albert Einstein. Thank you, sir. I agree.

Mr. MONROE. Analogies do wonders in all of science, especially in quantum mechanics. I agree with Dr. Franklin's statement that finding analogies, you can teach the concepts to young children in elementary school. I totally believe that.

Here is an analogy for a qubit. It is a coin, imagine a coin, when we flip a coin, it is in a definite state all the time, but we might not know what it is or want to know all the details, but if you think of a coin as being quantum in, say, both heads and tails at the same time. Imagine now it is in a black box and you are not looking at it, so it is both heads and tails at the same time, but I want to control that coin, I want to maybe flip it. Let's say it is a weighted coin, so it is 90 percent heads and 10 percent tails. I want to flip the odds to be 90 percent tails and 10 percent heads. Well, we can do this from the outside world by just turning the box around, in a sense.

Mr. KINZINGER. Actually, that makes sense.

Mr. MONROE. So we don't know what the state was, we didn't measure it, we didn't betray the quantum system but we controlled it. And so to Dr. Putman's point, this is pretty exotic hardware, because the quantum stuff is inside and we have to keep our distance when we control it. We have to do things without looking and put quotes. What it means is that the system is so extremely well isolated that we don't get the information out. So a quantum computation involves manipulations like that. They can be much more complicated. Flip one qubit depending on the state of another, for instance, without looking—and it is possible to do that in a very small group set of technologies. Then at the end of the day, you unveil, you open the box, and you measure only one state, but it could be lots and lots of bits and that one answer could depend on exponentially many paths, exponentially many inputs in the device. As Mr. Brett mentioned, this can be put to use for real world problems, and logistics, and so forth.

Mr. KINZINGER. Awesome. Well, thanks. Nice work. I yield back.

Mr. LATTA. That is a large statue of Albert Einstein down the street, Mr. Vice Chairman, in front of the State Department. So you might get your statue there some time.

The chair recognizes the gentleman from Kentucky for 5 minutes.

Mr. GUTHRIE. Thank you very much.

That was a good example. I am trying to understand this and move it forward. This is kind of in my family. I didn't get any of the genetics, but have a nephew at the University Chicago in the physics department going to CERN this summer. So he is in a different league than I am. So some of the discussion we hear is like he and my son talking to each other during Thanksgiving or whatever, he is a computer science and math person as well, working in Chicago, but in the financial industry.

So I guess I am trying to figure out, or take in the theory, not really theory but the things that you are talking about that is hard to understand and make it to the real world.

So first, Mr. Brett, I will go to you. Can you tell us a little bit about what your company is doing in the financial services area? That is where my son is in, in algorithms. He is in one of the quant guys, I guess, in hedge funds, but how quantum computing would be an improvement over classical computing. What difference does this make, I guess? And what is your firm doing in financial services to be better than what is currently there?

Mr. BRETT. Thank you, Congressman. The financial services sector is already a huge user of cloud compute technology. So they are using immense amounts of computational work, either on public clouds, like AWS or Microsoft, or their own private service. And it is important to understand that quantum computers won't replace classical computers. They will exist side by side in the cloud. And quantum computers will run some the algorithms that they are most efficient at. So in a mixed compute environment of financial services company will run their daily operation around compliance, portfolio, optimization, understanding risks, but send some of the algorithms that are in the program to the quantum computer to be most efficiently run.

Mr. GUTHRIE. So what does that do different? In what way? How is that?

Mr. BRETT. So a quantum computer cannot allow us to solve some particular algorithms that cannot be solved on a classical machine in a useful timeframe. So we might be able to solve it over many, many years, or decades even, but what if we need the answer today? A quantum computer can help give us that speed advantage.

Mr. GUTHRIE. So why wouldn't it completely replace the classical update if it gets to that?

Mr. BRETT. It is too expensive, and also, there are some problems that quantum computers can't do. So quantum computers aren't particularly good, for example, at addition or subtraction, so we leave those to classical computers to do that work, and quantum computers specialize in what they are good at, which is optimization problems.

Mr. GUTHRIE. OK. This is a little harder for my mental capacity to understand something that can't do math, but can do other things, but simple math, I guess. So I am at addition subtraction level. I am not an Einstein like my friend, Mr. Kinzinger.

So Dr. Putman, in your testimony—I am trying to get back to reality—you did find the problem scarcity as one that quantum computing could help solve. And how might quantum computing disrupt traditional models of how resources are created and distributed in an economy?

Mr. PUTMAN. Thank you, Congressman.

Often, there is an enormous amount of waste in the way that we currently produce anything. This is not due to humans caring to produce waste, or a problem with this in general, it is due to our inability to comprehend and to simulate and to build. The more precise we are on a molecular level, the better we are at being able to do that. The examples that I used such as fertilizer, for instance, or of material science, a classical computer gets very rough examples of how to actually build something and understand what is going on molecularly. The more we are able to do that in ways that quantum computing allows, the more we can explore the space of possibilities. When we explore that space and understand it, it gives us a chance to create it. This just is not possible with humans alone, or with our classic computing systems. This applies to many areas that we could go on about.

Mr. GUTHRIE. OK.

Mr. PUTMAN. But certainly in manufacturing, it creates an entirely different way of doing manufacturing when we are precise.

Mr. GUTHRIE. OK. When we are doing votes in the cloakroom, I am going to let Adam further explain this to me. So I am willing to do that moving forward. Thanks.

I understand it is just such a difficult concept for people not in your space to understand, but it is exciting stuff. I have about 30 seconds. But Dr. Monroe, I know Dr. Putman mentioned about qubits, how many in quantum computers. But here is a question, is what is the signal-to-noise ratio per qubits? For which I mean, how many qubits does one need for a useful quantum computer? And of those, how many would actually be performing calculations?

Mr. MONROE. Ah, thank you for the question. I probably won't answer it to your liking.

Mr. GUTHRIE. To my understanding. Probably to my liking, just not to my understanding.

Mr. MONROE. We don't know yet how many qubits are needed for something useful that can displace conventional computers. However, a relatively small number of about 75 or 100 qubits is enough to show certain, very esoteric and narrow, maybe not useful, problems can be solved that cannot be solved using conventional computers. That doesn't mean they are useful. And so it is sort of a proof of principle, and that is going to happen very soon. But then the question after that happens, once we are beyond that milepost, the idea is to find something useful. And I think the only way to find something useful is to put these devices in the hands of people that don't know or care what is inside the devices, sort of like my smartphone. I don't really want to know what is inside. And to build these devices, I use the word "exotic" a lot; it is exotic hardware to build these devices. It takes a new generation of engineers. And it may be that we need hundreds, it may be that we need thousands or more of these qubits for something useful.

Mr. GUTHRIE. Thank you. I yield back.

Mr. LATTA. Thank you. The gentleman yields back. The chair recognizes the gentleman from Massachusetts for 5 minutes.

Mr. KENNEDY. Thank you, Mr. Chairman. Thank you for calling this important hearing. Thank you to our panelists today for being here. From what I can tell, all of you clearly believe in the future of quantum computing, that is great. Still, there are some very smart people out there who are skeptical that quantum computing won't ever become a practical reality. They say for instance that quantum computers are too unstable and error-prone to be harnessed for real world problem-solving.

Dr. Franklin, and anybody else who wants to comment on this, how do you respond to those skeptics? And what do you see as the biggest hurdles to a real world application for quantum computing?

Ms. FRANKLIN. Well, I think that if we made decisions based on that assumption then we clearly won't build a quantum computer. And if we are wrong, the stakes are far too high, because other countries will make one, and then they will be able to decrypt all of the messages—there are so many advantages, if it can be realized, that we don't want to be the ones who decide early and then are wrong. And we are making great strides.

Yes, right now, quantum computers are very small and very error-prone. And so physicists like Dr. Monroe are working on making them more stable, larger, longer running. And then there is the piece in between. It used to be that classical computers were very large in size, but very few bits and couldn't do very much. What we could do in the 1980s in supercomputers is on your smartphone now. And so we don't know what can be done, and we need to put the resources in to see where we can go, because the stakes are just too high.

Mr. KENNEDY. Dr. Monroe.

Mr. MONROE. I would add on to that, I think, the question the same technology we used to build quantum computers is also used for quantum communication and quantum sensors. And these are real-world applications that can be and are deployed right now.

On the sensor side, the ability to detect signals remotely, the optical techniques, or to detect mass, which means if you are underwater, you need to know where you are to navigate. If you are exploring for oil, you need to know what is underneath the rock. Is it oil? Is it water? Those sensors, the limiting signal to noise in those sensors is given by quantum mechanics, we actually exceed those seemingly fundamental limits, in some cases. I mention this because that same type of technology is used in quantum computers. I do believe that quantum computers are most disruptive of all these technologies, but along the path toward that, there will be other spinoffs.

Quantum communication is largely photonic, optics as we communicate now over long distance. You can also do this with single particles of light, photons. And photons can—these are wonderful quantum bits that can be used for quantum computing in some cases, but they can also be used to send data in ways that are hack-proof. If somebody tries to observe it, they change it, they can cut the line always, they destroy your communication, but they can't intercept it and understand it. So what does that have to do with quantum computing? If you are going to build a big quantum computer, it is going to be a network. It is going to have optics that fiberize little modules on a computer. None of this hardware really exists today to couple those photons to quantum memories in qubits. I would hang my hat on quantum computing being the most disruptive of all of them, but along the way many other technologies related.

Mr. KENNEDY. Dr. Franklin, you started to get into something that I wanted to ask—have got about 1 minute and 15 seconds left or so—encryption and the application of quantum computing to encryption and the potential for it to render in encryption obsolete. Can you talk me through that and what is the reality of that?

Ms. FRANKLIN. Yes, so encryption is all based on the idea that doing one operation is much harder than undoing it. It is a lot easier to multiply two numbers than it is to divide or factor a number. And so there is a quantum computing algorithm that actually takes a lot this and so that is not one of the near-term applications, but that makes it so that factoring the very numbers that are used to create those keys that are required to encrypt and decrypt, can be broken down very easily to their components, and their components are necessary to decrypt. And so if we get a quantum computer of that size, we are going to have to figure out completely new encryption algorithms that use mathematical functions that a quantum computer cannot do quickly.

Mr. KENNEDY. And is that time horizon, can you put a time horizon that actually takes a lot on that.

Ms. FRANKLIN. Chris?

Mr. MONROE. So this factoring problem, it is among the hardest out of there. You probably need tens of thousands of qubits, quanta bits and millions, or more, maybe even billions of operations. I will say, however, the problem is so important that you need to know—you don't want a quantum computer just to break messages. You want to know when one exists, that impacts how you encrypt now. We are talking political time scale, so if a computer exists in 30 years, that could impact how you encrypt things now, so you may want to be ahead of the game and change the encryption standards based on when a quantum computer will exists, and it is very, very hard to predict 30 years in the future what technology will bring us.

Mr. KENNEDY. If you can predict what is going to happen tomorrow, we should hang out more. Thanks very much. I yield back.

Mr. LATTA. The gentleman yields back. The chair recognizes the gentleman from Florida for 5 minutes.

Mr. BILIRAKIS. Thank you. Thank you, Mr. Chairman. I appreciate it. I will be as brief as I can to get everyone else in.

Mr. Brett, in your testimony, you identify three classes of applications that are possible in the near term, and I know you talked about these earlier.

Can you briefly explain why you expect those to be the most possible in the near term?

Mr. BRETT. Thank you for the question, Congressman.

With the earliest quantum computers, like the type that Chris Monroe is building at the moment, the first versions of these won't have error correction on them. And so the kind of applications that we can build need to able to accommodate errors and the potential imprecisions that come along with that. And so the kind of applications that are best suited to early stage quantum computers are those which are the most tolerant or resilient to error. And those are things like optimization problems, working with chemical simulation and machine-learning-type problems because the kind of algorithms we run on there are based on probabilities. And so we already get a probabilistic-type answer from classical computers out of that, and a quantum computer best matches what is possible there.

So the early stage applications are those that are more probabilistic, more resilient to error. And then, as the computers become more capable and better, we will be able to take on the harder type problems that require error correction around that.

Mr. BILIRAKIS. OK. Thank you.

This next question is for the panel. Will quantum computers be something that anyone can use, which is important, or will it require a highly sensitive operating environment, such as that only a handful would be able to operate?

Why don't we start from over here, from afar, please.

Mr. PUTNAM. Thank you, Congressman.

It has to be something that has user interfaces that are possible for everyone in order for it to be incredibly relevant. The physics and the hardware behind it, just like the hardware and the physics behind everything else we do, will have a lot of specialists involved with it. But it is important for us, it is a challenge and important for us that this is something that is in the hands of anybody.

So I think absolutely.

Mr. BILIRAKIS. So it is not going to require additional training or anything like that——

Mr. PUTNAM. Well, only to the extent that everything we do requires some amount of training until it becomes so commonplace that it becomes natural.

Mr. BILIRAKIS. All right. Very good.

If you could comment on that, please.

Mr. MONROE. Sure. Thank you for the question. I will be very brief.

I think the answer is it will be very much like current computers. The use of current computers to program in certain languages takes some training. It will be a different type of a language.

But the fact that there are individual atoms in the device at the end of the wire will be lost on the user, and it should be. They don't need to know that. They need to know the rules, the programming language, and what it can solve.

So I think the answer will be affirmative.

Mr. BILIRAKIS. Very good.

Ms. FRANKLIN. Yes. I think there are sort of three levels. One is the hardware. We are seeing quantum cloud computation, so I think it is likely that you won't buy one and maybe have it in your pocket. But at least the cloud resources will be there.

And as a user, you may not even know that you are using a quantum algorithm. The services that you use will have programmers who have made a combination of quantum algorithms and classical algorithms and send that computation to the cloud. When you do a Google search, something like a hundred programs respond off for that one search to figure out, is it an airline, is it a mathematical—all these different things.

In terms of the ability to program it, that is where the most work has to come in. Right now, the amount of expertise needed to program these is insane. It is a high level of expertise. But that is how it was when the first women programmers were given a spec of the first computer and said, "Here. Program this," right?

They did it from the hardware. That is essential where we are. It is very tied to the hardware. So we need to figure out what are those abstractions that are still useful computingwise but also understandable to people who are the current level of a traditional computer scientist or even an application developer.

Mr. BILIRAKIS. OK. Very good.

Please.

Mr. BRETT. Thank you for the question.

I fully agree with my fellow panelists that we believe that you shouldn't need to have a degree in quantum physics to program a quantum computer. And so that is exactly what we are doing at QxBranch, is building the software that enables regular software engineers and computer scientists to create applications and to do so without needing to know the intricacies of what exactly is happening down at the molecular scale.

I will also point out that quantum computing is already becoming accessible. So, in the cloud today, IBM, for example, have released a quantum computer that we can all access. It is at IBM.com/quantum. We can go there this afternoon, do a short course on quantum computing programming, and start to build up that knowledge and understanding of what is possible and start to build those skills for the future.

Mr. BILIRAKIS. All right. Very good.

I yield back, Mr. Chairman. I appreciate it.

Mr. LATTA. Thank you. The gentleman yields back.

And the chair now recognizes the gentleman from West Virginia for 5 minutes.

Mr. MCKINLEY. Thank you, Mr. Chairman.

And, again, thank you for continuing to put before us in our hearings some very provocative thoughts and through this disrupter series. We have dealt with, over the past 2 years, some very curious and innovative and, for me, as one of two engineers in Congress, exciting possibilities where we might go with this. So I am fascinated with it, but I am also—I am sorry that the other side of the aisle didn't show up today. But I was curious to hear more of what Kennedy was talking about, the skepticism, because when I looked a little into that, there is some skepticism. And one of the articles I was reading a couple days ago had to do with reliability of the results.

So I know from doing my own engineering calculation that we can—at the end of the day, we know whether that result makes sense. But what happens when we use quantum computing if we get—and I think, Monroe, I think you might have said if they are error prone, do we rely on the result? How do we question it? If we are relying on our computers to give us the answer and then we get the answer, how do we know it is wrong? Or how do we know it is right because of all the variables that you have all talked about here?

Do you want to answer that?

Mr. MONROE. Yes. Thank you for the question. A very good one.

I think it speaks to the—so far, the limited research of what a quantum computer is useful for. There exist problems, like the factoring problem; you can easily check it. Fifteen is equal to five times three. When that 15 is a huge number, you can't do it using regular computers, but you can multiply your answer together to check and see if it worked.

Mr. MCKINLEY. Talk about encryption.

Mr. MONROE. Yes. If you can factor large numbers, you can break the popular types of encryption algorithms out there now. And if you think you have a code breaker, you can check it quickly.

And so almost all applications of quantum computers, they are either checkable against some standard, or they could be better than any classical approach. Say, for instance, in the financial market or some logistics problem where there is a cost function, it is in real dollars, and you are trying to minimize the cost subject to an uncountable number of constraints and configurations of the marketplace, for instance.

Well, if your quantum computer comes up with a result that has lower costs than any conventional computer could compute, then you found a different solution.

Mr. MCKINLEY. OK. A couple quick points here to follow back up.

I can see there is a lot more—again, fascinating. I want to read more. This whole idea has triggered me to do a little bit more research in this as well.

But let's talk about the timetables. Right now, yes, some elementary units are out there. But what is the metric? Where is the goal? Where do we want to achieve? And how do we know whether we are there? And, secondly with that, what is the role of Congress on this?

Is this just more money into research? You talk about building plants or facilities so that we could build these qubits? Is this what it is? What role is government?

Mr. MONROE. Well, thank you for the question.

Again, I mentioned the idea of a national quantum initiative and the crux of that initiative is to establish, indeed, a small number of hub laboratories. They are not new buildings.

Mr. MCKINLEY. These are hub zones or hub lab—yes.

Mr. MONROE. Yes. Quantum innovation laboratories. They could be at existing university, Department of Energy, or Department of Defense laboratories, collaborations with industry, hubs where students and industrial players are all in the same sandpit.

And each of these hubs—there will be a small number of them—they would focus on a very particular aspect of quantum information or sensing or quantum computing. Maybe develop particular brand of qubit, for instance.

And the point here is to foster the generation, a new generation, of engineers in that particular technology. Industry will be able to connect more vitally with the university and a potential workforce. Students could have ——

Mr. MCKINLEY. Are we trying to develop a standard qubit?

Mr. MONROE. I think it is too early to do that now. I think we have several different technologies, and they will probably all find different uses. Sort of like now we have a CPU on a computer. We have memory. There are all kinds of different components, different hardwares that are good for different things. And we will probably see that in quantum as well.

Mr. MCKINLEY. OK. Again, what is the timetable?

Ms. FRANKLIN. Well, I think it depends on the application. Encryption might be 30 years off. But we have got 50 qubit machines now that are growing. And so these near-term applications, like optimization, are on the horizon, maybe 5 years. The hardware is coming along very quickly. I think that—and some software, but this is the first I have heard of a software company. I am very excited.

But that middleware. There is software that needs to be created that makes it so that algorithms that assume perfect hardware can be modified to use this near-term hardware so that we don't have to wait as long and can help close that gap between the assumptions of the software and the realities of the hardware.

Dr. MCKINLEY. OK. Thank you.

I yield back.

Mr. LATTA. Thank you. The gentleman yields back. And the chair recognizes the gentleman from Indiana for 5 minutes.

Mr. BUCSHON. Well, thank you for being here. It is a fascinating subject. I was a surgeon before, so I am kind of a scientist. I am interested in this. My daughter is sophomore at Cornell in computer science. So she is, obviously.

I am going to take a little different pathway here on questioning and stay away from the technical stuff and go toward research funding. And I was on a committee before that had jurisdiction over National Science Foundation. I am from Indiana. I went to all the universities and talked to the NSF funded researchers. And the one thing that I found is—first of all, I support that, right? I am a big supporter of research. One thing I found is, if I said, "Hey, tell me why what you are doing should continue to get funding from the National Science Foundation." Just a simple question, right? I found probably 90 percent of the people that I spoke to couldn't, in a really tight way, explain that. And for me, they can explain it in complex way. And I am like, "Oh, yes. I get it."

But people like me have to explain this to 700,000 people that we represent in a way that if we are going to justify Federal dollars and taxpayer dollars, we have to be able to give a so-called elevator speech and say—and one example, I think this is 4 or 5 years ago that was kind of in the press was about a funded researcher—and this is not a criticism—that was having seniors play video games. And so it got in the press, and people said, "Well, why would you fund that?"

Well, as it turns out, it was Alzheimer's research. You see what I am saying? And very valid, very important research. But to try to explain that, when it is written in a line, government funds video game; having people be better video game players doesn't play very well, and so people like me have a hard time explaining that.

So I guess what I am getting at is—and I guess this will be primarily for the people from the universities—is what is your pitch for more funding for quantum computing? That is something, you have already explained it to me, and I get it. But if we are going to explain it to the broader Members of Congress and our constituents, how do we explain that, why we should do that?

Does that make sense?

Mr. MONROE. Yes, it does. Thank you for the question, Congressman.

Yes. I did speak at length about these very targeted type hubs. And it should be sort of self-evident what these are about. They are developing technology. They are more technology centers.

But there must be an undercurrent of foundational research, and this is something the National Science Foundation, they are a very special agency in that regard. Fundamental research is very inefficient, and we can never tell what is around the corner. And you can never predict what is going to hit and what——

Mr. BUCSHON. Yes. You don't know what you don't know, right?

Mr. MONROE. Yes. That is right.

And as the Science Foundation takes all-comers and they will have to play an important role in any national quantum initiative in the future, because there may be quantum technologies that don't exist now. And maybe in 10 years, due to some surprise and some weirdo material, we see that, oh, they behave as wonderful qubits.

So, again, it is too bad that it is inefficient, but the home runs are far reaching, and this field will probably rely on those in the coming decades.

Mr. BUCSHON. Dr. Franklin.

Ms. FRANKLIN. Yes. It depends on how long you are in the elevator. I think the pitch for quantum computers starts with the killer apps of drug design for Alzheimer's, right? It is projected that 40 percent of the Medicaid budget is going to go toward Alzheimer's by 2040.

So, these are real problems. And if we could model the molecules and figure out exactly how nitrogen gets fixed and put into fertilizer, we could have much lower energy, food production. And so these are big deals, right? And those are things that can't be done with classical computing.

Then the next step is you have to tie the researchers to those problems. And that is what sometimes researchers aren't good at conveying. But that is why I do think that the calls—we are at the cusp of commercialization, and it might be an appropriate time for even the NSF funding to be looking at the broader impacts more. So our group is making tools that everyone can use, and so that is something that we can hang on to, right?

Mr. BUCSHON. OK. The other thing I am interested in is technology transfer, obviously, because that is, as you know, a huge problem, not only in this area but across the research fields. What percentage of research goes, that is probably potentially commercially useful. It just goes into a black hole.

And I know I am short on time, but maybe, Mr. Brett, you can comment, how we can do better on technology transfer because it is a pretty big problem, really.

Mr. BRETT. Thank you, Congressman.

And we agree. As a small business that is looking to commercialize some of these innovations, how do we get access to some of the great work that is being done at the universities and to incorporate that?

Mr. BUCSHON. Because it is proprietary, right, sometimes? That is some of the problem maybe, right? People are willing—if they put the research out there, they are worried somebody will steal it, so to speak, right?

Mr. BRETT. An approach that has been particularly successful for us is being able to partner with universities on research grants and so for—as an R&D business to also participate in the collaboration of that research and contribute to the science and the publication around that and share some of that intellectual property on a joint project together. And I think that that cross between the commercial sector and the research sector working together on funded proposals will enable a lot of that technology transfer.

Mr. BUCSHON. OK. My time is up.

I yield back.

Mr. LATTA. Well, the gentleman yields back.

And I first want to thank our panel for being here today. One of the great things about serving on this committee and because we do have such wide jurisdiction, I always say it is like looking over the horizon 5 to 10 years, that we hear it here first. And we want to make sure that our nation is on that cutting edge.

And I am going to say something about some of our folks that were asking questions. They were a little bit on the modest side. I have a former Air Force pilot, a West Point grad, an engineer, and cardiothoracic surgeon over here. So they are not limited in knowledge.

But what you gave us today was very, very informative because, again, we have to make sure that, as we go forward as a committee, that we are making the right decisions as we go on.

And the gentlelady also would like to make a comment too. So I just want to thank you all. But I will finish up the ending, but I will let the gentlelady right now.

Ms. SCHAKOWKSY. Thank you.

China is building a $10 billion quantum lab right now. And they expect to be finished by 2020. And the EU is investing about $2 billion in advanced quantum technology. So I think one of the answers in terms of why we should be serious about making investments may be decryption is—and encryption is—some decades away. But from a national security perspective, I think that there are a lot of reasons that we should take this seriously and make the investments. And, of course, all the practical things about agriculture and pharmaceuticals, et cetera, is very, very important, disease cures.

But it seems to me that, despite maybe some skepticism, there is enough evidence right now that really ought to be an important priority. So I just want to thank you very much. You really did enlighten me.

Thank you.

Mr. LATTA. Thank you. The gentlelady yields back.

And seeing that we have no further members that are going to be asking questions today, pursuant to committee rules, I remind members that they have 10 business days to submit additional questions for the record. And I ask that witnesses submit their responses within 10 business days upon receipt of questions.

And, without objection, the subcommittee will stand adjourned. Thank you very much for attending today.

[Whereupon, at 10:34 a.m., the subcommittee was adjourned.]

[Material submitted for inclusion in the record follows:]

PREPARED STATEMENT OF HON. GREG WALDEN

Good morning and thank you to our witnesses for appearing before the subcommittee today to discuss quantum computing and your work in the field. Part of our job at the Energy and Commerce Committee is to explore ideas and issues that have the potential to radically alter the way Americans work and live.

Our Disrupter Series allows us to spotlight the emerging technologies that might one day fundamentally change the status quo. Quantum computing is just one such innovation that is still on the cutting edge of development.

Quantum computers could one day revolutionize materials simulation, data analysis, medicine, machine learning, communications, and countless other fields. At the same time, challenges remain to the development of quantum computers because of their complex and unique operational needs.

Nevertheless, the race is on and the stakes are high. The U.S. is locked in competition with China, Russia, and Europe to develop a practical and commercially available quantum computer.

Research into this promising technology is happening across the country. America's universities are leading the way, with advanced research taking place at dozens of institutions nationwide.

One such effort is at my alma mater, the University of Oregon, where Nobel-prize winning physicist David Wineland and other members of the physics department are wrestling with this complex project. Just last month it was announced that researchers from U of O, along with those from Duke, UC Berkley, MIT, Johns Hopkins, and others, have received funding from the U.S. Army Reserve Office to help develop quantum technologies. [1]

The mind-bending ideas inherent to the physics of quantum computing are difficult to grasp.

Particles that exist in multiple states simultaneously—light and matter existing as both particle and wave; entangled atoms that can share their physical connection even when separated across the universe —these are complicated topics. As the great Danish physicist Niels Bohr has been quoted as saying, "Anyone who is not shocked by quantum theory has not understood it."

This makes it all the more remarkable that efforts to harness these principles for widespread use are well underway. I look forward to hearing from our witnesses about how far we have come in developing a practical quantum computer, and how far we have yet to go.

The experts before us today will help the committee gain a better understanding of the complicated physics that underlie these efforts, and how important it is that America remains at the forefront of this innovation.

The entrepreneurial spirit of the United States has no equal. Here at the Energy and Commerce Committee, it is our goal to support U.S. innovation and the jobs and economic growth produced as a result. Every day, American innovators accomplish things that were previously thought unimaginable.

I thank the witnesses for your time today, and the important work you are doing.

Mr. Chairman, I yield back the balance of my time.

PREPARED STATEMENT OF HON. FRANK PALLONE, JR.

I do not pretend to understand some of the concepts at the core of quantum computing. It is reassuring to me that even Einstein struggled with these ideas.

Fortunately, I do not need to be an expert to understand that quantum computers may someday be able to perform calculations far beyond the capacity of even the fastest supercomputers. I also appreciate that these computers have great potential to solve many now- unsolvable real world problems.

The development of life-saving drugs is just one example. Today, new drug development takes years, produces many false leads, and costs billions of dollars. A quantum computer could be used to predict how molecules, proteins, and chemicals interact with each other and with human cells. The result: safer more effective drugs, for treating Alzheimer's, cancer, or opioid addiction, get to market sooner and at more affordable prices.

The technology has many other promising applications for agriculture, climate study, financial analysis, supply chain management, traffic control, and more.

At the same time, quantum computing could open a Pandora's Box for security, rendering all modern encryption obsolete. In theory, a quantum computer could someday crack codes in mere seconds that would take a traditional computer thousands of years to decipher. That milestone would completely change the global balance of power.

I am looking forward to learning more from our panelists about just how theoretical these applications are, and how long it will take for them to become a reality. Despite dramatic progress in the past two or three years, there are still major hurdles to overcome before fully functional quantum computers are solving real-world problems.

We may not know with certainty when quantum computing will be a reality. We may not be able to predict all of its potential uses. We can, however, identify and address current obstacles to progress. Two clear obstacles are funding and workforce training.

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[1] https://edgylabs.com/lsu-receives-federal-grant-to-develop-quantum-technologies.

The federal government must support quantum computing research as well as basic scientific research. And those dollars must be continuous and predictable.

We also must be mindful that other countries are investing heavily in quantum computing and we must stay globally competitive. China, for instance, is building a 10 billion-dollar national lab by 2020, and the European Union plans to invest two billion euros over the next 10 years.

People are just as essential as dollars, but right now there is a profound gap in education and training. The field needs more computer scientists, mathematicians, and engineers with a solid grasp of quantum mechanics. Undergraduate and graduate programs that combine these disciplines, however, are rare. And students of all ages must be exposed to the principles of quantum computing from an early age all the way through graduate programs. We are fortunate to have Professor Diana Franklin here today to speak to the education and training gaps. Mr. Chairman, I look forward to hearing from her and all of our witnesses.

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